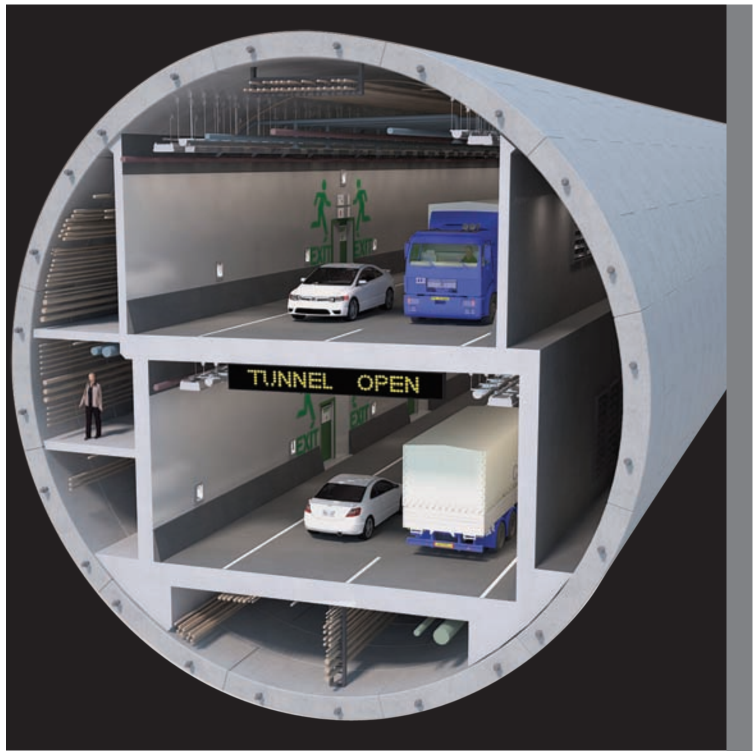
ALASKAN WAY VIADUCT REPLACEMENT PROJECT

2010 Supplemental Draft Environmental Impact Statement

APPENDIX P Earth Discipline Report



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U.S. Department of Transportation
Federal Highway Administration

Washington State Department of Transportation

City of Seattle

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Alaskan Way Viaduct Replacement Project

Supplemental Draft EIS
Earth Discipline Report

The Alaskan Way Viaduct Replacement Project is a joint effort between the Federal Highway Administration (FHWA), the Washington State Department of Transportation (WSDOT), and the City of Seattle. To conduct this project, WSDOT contracted with:

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In association with:
Coughlin Porter Lundeen, Inc.
EnviroIssues, Inc.
GHD, Inc.
HDR Engineering, Inc.
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Parametrix, Inc.
Power Engineers, Inc.
Shannon & Wilson, Inc.
William P. Ott Construction Consultants

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ACRONYMS AND ABBREVIATIONS

bgs	below ground surface
BMP	best management practice
CIP	cast-in-place
EBI	Elliott Bay Interceptor
Ecology	Washington State Department of Ecology
EIS	Environmental Impact Statement
EPB	earth pressure balance
FHWA	Federal Highway Administration
GEDR	Geotechnical and Environmental Data Report
NEPA	National Environmental Policy Act
Program	Alaskan Way Viaduct and Seawall Replacement Program
project	Alaskan Way Viaduct Replacement Project
Sea-Tac	Seattle-Tacoma (International Airport)
SPB	slurry pressure balance
SR	State Route
TBM	tunnel boring machine
TESC	temporary erosion and sediment control
WSDOT	Washington State Department of Transportation

Chapter 1 INTRODUCTION AND SUMMARY

1.1 Introduction

This discipline report evaluates the Bored Tunnel Alternative, the new alternative under consideration for replacing the Alaskan Way Viaduct. This report and the Alaskan Way Viaduct Replacement Project Supplemental Draft Environmental Impact Statement (EIS) that it supports are intended to provide new information and updated analyses to those presented in the March 2004 Alaskan Way Viaduct and Seawall Replacement Project Draft EIS and the July 2006 Alaskan Way Viaduct and Seawall Replacement Project Supplemental Draft EIS. The discipline reports present the detailed technical analyses of existing conditions and predicted effects of the Bored Tunnel Alternative. The results of these analyses are presented in the main volume of the Supplemental Draft EIS.

The Federal Highway Administration (FHWA) is the lead federal agency for this project, primarily responsible for compliance with the National Environmental Policy Act (NEPA) and other federal regulations, as well as distributing federal funding. As part of the NEPA process, FHWA is also responsible for selecting the preferred alternative. FHWA will base their decision on the information evaluated during the environmental review process, including information contained within the Supplemental Draft EIS and the subsequent Final EIS. FHWA can then issue their NEPA decision, called the Record of Decision (ROD).

The 2004 Draft EIS (WSDOT et al. 2004) evaluated five Build Alternatives and a No Build Alternative. In December 2004, the project proponents identified the cut-and-cover Tunnel Alternative as the preferred alternative and carried the Rebuild Alternative forward for analysis as well. The 2006 Supplemental Draft EIS (WSDOT et al. 2006) analyzed two alternatives—a refined cut-and-cover Tunnel Alternative and a modified rebuild alternative called the Elevated Structure Alternative. After continued public and agency debate, Governor Gregoire called for an advisory vote to be held in the city of Seattle. The March 2007 ballot included an elevated alternative and a surface-tunnel hybrid alternative. The citizens voted down both alternatives.

Following this election, the lead agencies committed to a collaborative process to find a solution to replace the viaduct along Seattle's central waterfront. This Partnership Process is described in Appendix S, the Project History Report. In January 2009, Governor Gregoire, King County Executive Sims, and Seattle Mayor Nickels announced that the agencies had reached a consensus and recommended replacing the aging viaduct with a bored tunnel.

The environmental review process for the Alaskan Way Viaduct Replacement Project (the project) builds on the five Build Alternatives evaluated in the 2004 Draft EIS and the two Build Alternatives evaluated in the 2006 Supplemental Draft EIS. It also incorporates the work done during the Partnership Process. The bored tunnel was not studied as part of the previous environmental review process, and so it becomes the eighth alternative to be evaluated in detail.

The Bored Tunnel Alternative analyzed in this discipline report and in the Supplemental Draft EIS has been evaluated both quantitatively and qualitatively. The Bored Tunnel Alternative includes replacing State Route (SR) 99 with a bored tunnel and associated improvements, such as relocating utilities located on or under the viaduct, removing the viaduct, decommissioning the Battery Street Tunnel, and making improvements to the surface streets in the tunnel's south and north portal areas.

Improvements at the south portal area include full northbound and southbound access to and from SR 99 between S. Royal Brougham Way and S. King Street. Alaskan Way S. would be reconfigured with three lanes in each direction. Two options are being considered for new cross streets that would intersect with Alaskan Way S.:

- New Dearborn Intersection – Alaskan Way S. would have one new intersection and cross street at S. Dearborn Street.
- New Dearborn and Charles Intersections – Alaskan Way S. would have two new intersections and cross streets at S. Charles Street and S. Dearborn Street.

Improvements at the north portal area would include restoring Aurora Avenue and providing full northbound and southbound access to and from SR 99 near Harrison and Republican Streets. Aurora Avenue would be restored to grade level between Denny Way and John Street, and John, Thomas, and Harrison Streets would be connected as cross streets. This rebuilt section of Aurora Avenue would connect to the new SR 99 alignment via the ramps at Harrison Street. Mercer Street would be widened for two-way operation from Fifth Avenue N. to Dexter Avenue N. Broad Street would be filled and closed between Ninth Avenue N. and Taylor Avenue N. Two options are being considered for Sixth Avenue N. and the southbound on-ramp:

- The Curved Sixth Avenue option proposes to build a new roadway that would extend Sixth Avenue N. in a curved formation between Harrison and Mercer Streets. The new roadway would have a signalized intersection at Republican Street.
- The Straight Sixth Avenue option proposes to build a new roadway that would extend Sixth Avenue N. from Harrison Street to Mercer Street in a typical grid formation. The new roadway would have signalized intersections at Republican and Mercer Streets.

For these project elements, the analyses of effects and benefits have been quantified with supporting studies, and the resulting data are found in the discipline reports (Appendices A through R). These analyses focus on assessing the Bored Tunnel Alternative's potential effects for both construction and operation, and consider appropriate mitigation measures that could be employed. The Viaduct Closed (No Build Alternative) is also analyzed.

The Alaskan Way Viaduct Replacement Project is one of several independent projects that improve safety and mobility along SR 99 and the Seattle waterfront from the South of Downtown (SODO) area to Seattle Center. Collectively, these individual projects are often referred to as the Alaskan Way Viaduct and Seawall Replacement Program (the Program). This Supplemental Draft EIS evaluates the cumulative effects of all projects in the Program; however, direct and indirect environmental effects of these independent projects will be considered separately in independent environmental documents. This collection of independent projects is categorized into four groups: roadway elements, non-roadway elements, projects under construction, and completed projects.

Roadway Elements

- Alaskan Way Surface Street Improvements
- Elliott/Western Connector
- Mercer West Project (Mercer Street improvements from Fifth Avenue N. to Elliott Avenue)

Non-Roadway Elements

- First Avenue Streetcar Evaluation
- Transit Enhancements
- Elliott Bay Seawall Project
- Alaskan Way Promenade/Public Space

Projects Under Construction

- S. Holgate Street to S. King Street Viaduct Replacement
- Transportation Improvements to Minimize Traffic Effects During Construction

Completed Projects

- SR 99 Yesler Way Vicinity Foundation Stabilization (Column Safety Repairs)
- S. Massachusetts Street to Railroad Way S. Electrical Line Relocation Project (Electrical Line Relocation Along the Viaduct's South End)

1.2 Summary

This Earth Discipline Report describes the geologic conditions present along the alignment of the Bored Tunnel Alternative. In addition, the operational and construction effects on earth and groundwater are discussed for the Viaduct Closed (No Build Alternative) and the Bored Tunnel Alternative. Mitigation measures and benefits for the Bored Tunnel Alternative are also presented.

1.2.1 Affected Environment

The project and Program elements are located in a highly developed corridor that includes buildings, utilities, roadways, railroads, and numerous other surface improvements. The subsurface geology encountered along the project alignment includes glacial deposits overlain by various thicknesses of recent native deposits (deposited through geologic processes) and fill (deposited by humans). Along most of the bored tunnel alignment north of Madison Street, the glacial deposits are located within about 30 feet of the ground surface. In general, the deepest recent deposits are encountered at the south end of the project in the south portal area. Recent deposits in the south portal area extend from about 30 to 90 feet below the ground surface. These recent deposits consist of loose to dense sand, silty sand, sandy silt, and soft to stiff clayey silt and silty clay. Within the fill deposits, debris such as wood and concrete are routinely encountered. The regional groundwater table was encountered along the project alignment at elevations ranging from about +10 feet to +20 feet (North American Vertical Datum of 1988 [NAVD 88]).

Liquefaction resulting from a seismic event is the geologic hazard with the greatest potential to affect the study area. This phenomenon occurs during ground shaking and results in a reduction of the shear strength of the soil (a quicksand-like condition). Liquefaction is a major concern both in the south portal area and along the waterfront. No liquefaction is anticipated along the bored tunnel or in the north portal area. Liquefaction can result in lateral spreading (ground movement on gentle slopes), landsliding on steep slopes, and lower vertical and lateral capacity for structure foundations. Buildings, bridges, and other structures founded on or in the liquefied soils may settle, tilt, move laterally, or collapse. The potential for and effects of liquefaction depend on the consistency and density of the soil, the grain-size distribution of the soil, and the magnitude and duration of the seismic event. Liquefaction will be considered in the design of the Bored Tunnel Alternative.

1.2.2 Earth and Groundwater Effects

Construction in the south and north portal areas of the Bored Tunnel Alternative would include retaining walls, foundations, excavations, and minor fills.

Construction would also include the tunnel boring activities and excavations at each end of the tunnel to install and remove the tunnel boring machine (TBM). Tunnel operations buildings would be constructed in the south and north portal areas. This section includes a summary of operational and construction effects on the earth and groundwater. All the identified operational and construction effects can be mitigated by proper design and construction methods.

Operational Effects and Mitigation

Most of the operational effects identified for the Bored Tunnel Alternative relate to potential ground movement adjacent to retaining walls and potential mounding of groundwater. Buildings, pavements, utilities, and other structures could be affected by the presence of new fills, walls, tunnels, and other new features. The development of a thorough and adequate design for the selected alternative would mitigate most of these effects. During the design process, site-specific mitigation measures would be identified to address potential operational effects on adjacent facilities.

Construction Effects and Mitigation

Most of the major construction effects identified for the Bored Tunnel Alternative relate to potential ground movement due to excavations and ground loss during tunnel boring. These ground movements could damage existing utilities, buildings, and other structures. Improper construction techniques could lead to excessive settlement, heave, vibration, or movement of adjacent buildings, pavements, utilities, or other structures. Mitigation measures identified in conceptual and final design would be implemented by experienced construction staff who would construct the project in accordance with the plans and specifications using best management practices (BMPs) specified by the Washington State Department of Transportation (WSDOT) and the City of Seattle. The collection of measurements at selected survey points would be a means of monitoring ground settlement and movement, which could predict potential damage to the existing facilities.

Cumulative Effects

The project team considered 39 projects near the project area for the Bored Tunnel Alternative for potential activities that could have cumulative effects related to earth and groundwater (see Attachment A). Cumulative effects for earth and groundwater are generally related to construction overlaps, and many of the adjacent projects would be constructed before or after construction of the Bored Tunnel Alternative. In addition, cumulative effects depend on proximity, and many of the adjacent projects are more than 200 feet from the Bored Tunnel Alternative. Cumulative effects related to earth and groundwater would be minimal for adjacent projects within 200 feet of the Bored Tunnel Alternative that would be constructed during the same timeframe as the Bored Tunnel Alternative.

No cumulative operational effects are anticipated. Many of the construction effects would also not contribute to a cumulative effect because BMPs would be used during construction of the Bored Tunnel Alternative and other adjacent projects, as required by city and state regulations. The primary cumulative effects related to earth and groundwater are potential ground loss during tunnel boring and potential water table drawdown due to excavation dewatering. Both of these effects can cause settlement of the ground surface, structures, utilities, and roadways. Mitigation measures identified for the project effects would be appropriate to address the cumulative effects.

Chapter 2 METHODOLOGY

The objective of the Earth Discipline Report is to describe the geologic conditions in the study area and identify effects that the Program could have on earth and groundwater.

2.1 Study Area

The study area for this Earth Discipline Report extends along the alignment of the Bored Tunnel Alternative and the other roadway and non-roadway elements of the Program, as shown on Exhibit 2-1. The affected environment and earth-related effects are discussed in detail for the Bored Tunnel Alternative within a study area of 200 feet from each side of the proposed bored tunnel alignment and portal areas. A more general discussion is provided for the other roadway and non-roadway elements.

2.2 Applicable Regulations and Guidelines

The following regulations and guidelines provided information used in the analysis of earth- and groundwater-related effects:

- American Association of Highway and Transportation Officials Bridge Design Specifications
- WSDOT *Bridge Design Manual* (M 23-50.02)
- WSDOT *Geotechnical Design Manual* (M 46-03.01)
- WSDOT *Environmental Procedures Manual (*M 31-11.05)
- City of Seattle, Environmentally Critical Areas Ordinance (Seattle Municipal Code, Chapter 25.09)

2.3 Data Sources

To gather the data needed to evaluate the affected environment and earth- and groundwater-related effects, project geologists and engineers reviewed existing subsurface data and data from additional soil borings drilled for the Program. Project files and archives from several sources were reviewed to obtain existing geotechnical subsurface information along the project corridor. These efforts were concentrated on sources where large amounts of information are already stored and easily accessed. In addition to obtaining information from WSDOT files, other data, primarily consisting of boring logs, were collected from the following sources:

- Shannon & Wilson, Inc., project files
- GEO-MAP Northwest

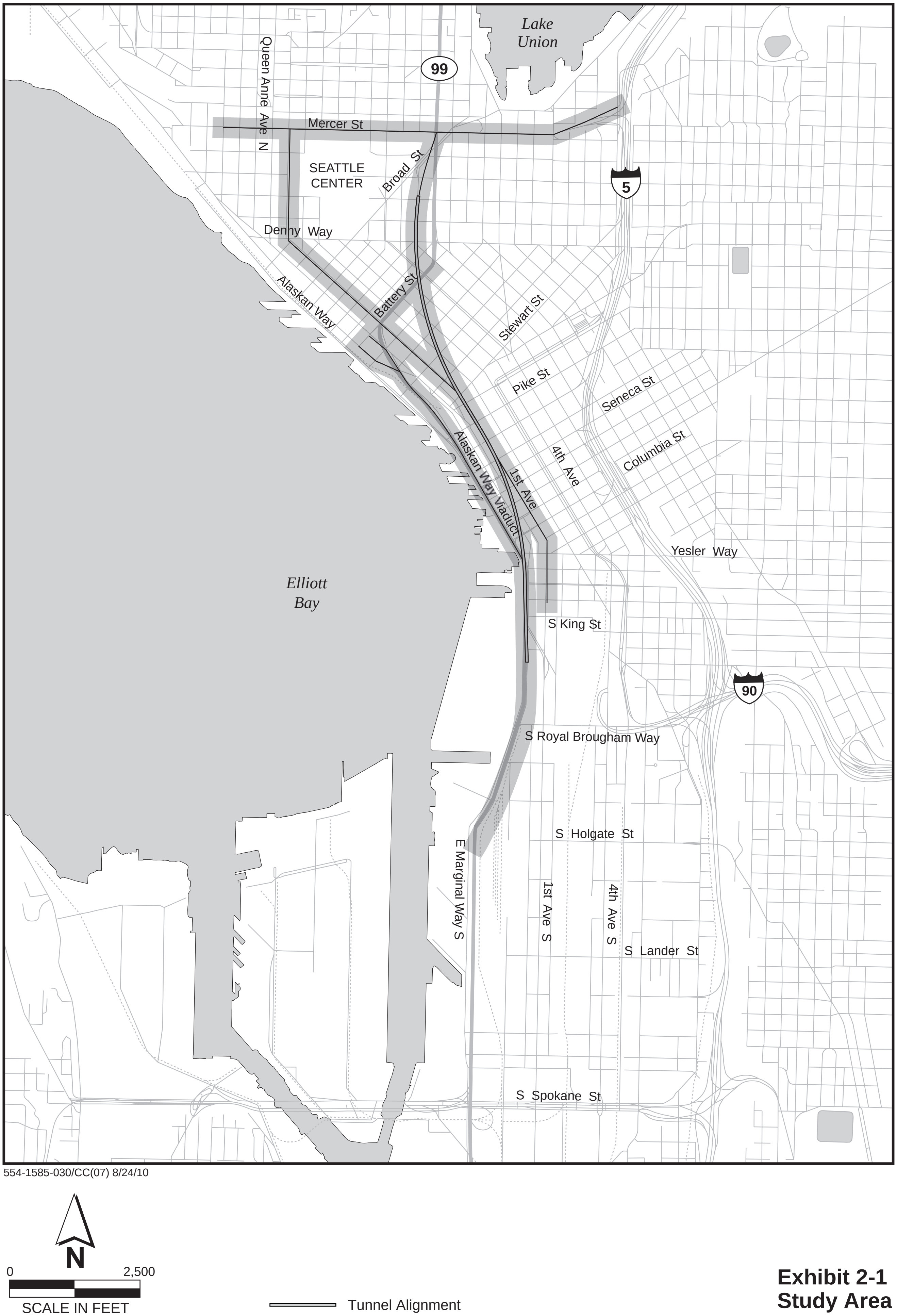

Exhibit 2-1
Study Area

- Seattle Department of Planning and Development
- Washington State Department of Ecology (Ecology)

In addition to obtaining site-specific subsurface data from various sources, published geologic literature was reviewed for the study area. These data include the following:

- City of Seattle Environmentally Critical Areas Ordinance and maps
- U.S. Geological Survey geology maps
- Washington State Department of Natural Resources maps
- Microzonation maps for the Seattle, Washington, metropolitan area

Field explorations have been performed for the Program between 2001 and 2010. For explorations located near the bored tunnel alignment, the results of the subsurface conditions and related field and laboratory testing were reviewed.

2.4 Analysis of Existing Conditions

Based on a review of subsurface earth and groundwater conditions, the existing conditions in the study area were analyzed. The analyses of existing conditions discussed in this discipline report include the following earth- and groundwater-related topics:

- Topographic and geologic setting.
- Tectonics and seismicity, including evaluation of the shallow crustal zone, deep subcrustal zone, and interplate zone.
- Site geology and subsurface conditions.
- Geologic hazards, including landsliding, erosion, fault rupture, liquefaction, and ground motion amplification.
- Groundwater, including regional groundwater systems and flow, site groundwater conditions, groundwater recharge and discharge, and current aquifer use.

These topics were analyzed to describe the earth and groundwater environment that may be affected by the project.

2.5 Analysis of Environmental Effects

The analysis of environmental effects was performed for the bored tunnel and portal areas. The feasibility and related effects of a twin bored tunnel were evaluated and are presented in a white paper prepared by Shannon & Wilson, Inc. (Shannon & Wilson 2008a). This paper outlines some of the earth- and groundwater-related effects of the proposed tunnel. Additional constructability issues and effects for the single bored tunnel are presented in a white paper prepared by Parsons Brinckerhoff (2009). These white papers were used in conjunction with updated subsurface information and experience with similar projects to analyze the effects of the project on earth and groundwater.

Preliminary analyses were performed to evaluate effects related to the following:

- Ground deformation
- Ground improvement
- Groundwater levels and flow
- Temporary and permanent retaining walls
- Excavations and dewatering
- Foundations
- Type and quantity of material excavated
- Erosion and sediment transport
- Stockpiles and soil disposal

The evaluations were based on preliminary engineering analyses and experience with similar projects and similar soil conditions. The effects for both construction and operation of the tunnel and related roadway elements were evaluated.

2.6 Determining Mitigation Measures

Mitigation measures were developed to avoid, minimize, and mitigate identified adverse effects on earth and groundwater. The selection of potential mitigation measures was based on the results of preliminary engineering analyses and experience with similar projects. Many of the effects can be mitigated by the use of BMPs. Some of the mitigation measures may have additional effects on the earth and groundwater environment (e.g., ground improvement); therefore, additional mitigation measures were presented in these cases.

2.7 Methodology for Cumulative Effects

Cumulative effects are effects on the environment that result from the incremental impact of the proposed action when added to other past, present, and reasonably foreseeable future actions. The cumulative effects analysis focused on the combined effects of the Bored Tunnel Alternative and other roadway and non-roadway elements included in the Program. In addition, other past, present, and reasonably foreseeable future projects that are anticipated to add to effects on earth and groundwater in the study area were evaluated.

The other roadway and non-roadway elements of the Program were qualitatively assessed for operational and construction effects on earth and groundwater. The roadway Program elements included in this qualitative analysis are the Alaskan

Way Surface Street Improvements (on the location of the former viaduct) from S. King Street to Pike Street, the Elliott/Western Connector from Pike Street to Battery Street, and the Mercer West Project (Mercer Street improvements from Fifth Avenue N. to Elliott Avenue). The non-roadway Program elements include the Elliott Bay Seawall Project, the Alaskan Way Promenade/Public Space to be built on the location of the existing Alaskan Way surface street, the First Avenue Streetcar Evaluation, and Transit Enhancements.

Other planned projects and developments in Seattle may add to the effects on earth and groundwater in the study area. The following projects were included in the cumulative effects analysis:

- Sound Transit University Link Light Rail Project
- Sound Transit North Link Light Rail
- Sound Transit East Link Light Rail
- Sound Transit Phases 1 and 2
- S. Spokane Street Viaduct Widening
- S. Holgate Street to S. King Street Viaduct Replacement Project
- SR 519 Intermodal Access Project, Phase 2
- SR 520 Bridge Replacement and High Occupancy Vehicle Program
- I-5 Improvements
- South Lake Union Redevelopment
- SR 99/East Marginal Way Grade Separation

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Chapter 3 STUDIES AND COORDINATION

3.1 Studies

Analysts obtained geologic data for the study area by collecting existing subsurface data and drilling additional soil explorations. Shannon & Wilson, Inc. has prepared the following reports for the Program summarizing the subsurface data and earth-related affected environment:

- August 2002 Geotechnical and Environmental Data Report (GEDR)
- October 2004 Seismic Ground Motion Study Report
- August 2005 GEDR
- April 2006 Utility Geoprobe Report
- April 2007 GEDR for Electrical Utility Explorations
- April 2007 Geotechnical and Environmental Data and Dewatering Feasibility Report
- October 2007 GEDR for Phase 1 Archeological Explorations
- December 2007 GEDR for Phase 1 Electrical Utility Explorations
- December 2007 GEDR for Utilidor Explorations
- November 2008 Review of Historic Information Report
- December 2008 GEDR for S. Holgate Street to S. King Street Viaduct Replacement Project
- June 2009 Geotechnical Characterization Report for S. Holgate Street to S. King Street Viaduct Replacement Project
- January 2010 Draft GEDR, Central Waterfront Tunnel
- March 2010 Ground Movements Interim Letter, Central Waterfront Tunnel

Data summarized in these reports were reviewed to develop the affected environment section of this report and to identify operational and construction effects, mitigation measures, and benefits of the Bored Tunnel Alternative.

3.2 Coordination

This report was prepared based on subsurface data collected by Shannon & Wilson, Inc. Archived information was obtained from WSDOT, the City of Seattle, and King County. No other coordination with other agencies or companies was necessary in the development of this report.

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Chapter 4 AFFECTED ENVIRONMENT

The subsurface conditions along the study area were evaluated by reviewing available subsurface information and performing additional subsurface explorations. This information was used to develop a description of the existing geologic conditions (topography, soils, groundwater, and hazards) that may be affected by the Bored Tunnel Alternative and related Program elements.

4.1 Topographic and Geologic Setting

The study area is located in the central portion of the Puget Sound Basin, an elongated, north-south depression situated between the Olympic Mountains and the Cascade Range. Repeated glaciation (glacial events) of this region, as recently as about 13,500 years ago, strongly influenced the present-day topography, geology, and groundwater conditions in the Seattle area. The topography is dominated by a series of north-south ridges and troughs formed by glacial erosion and sediment deposition. Puget Sound, Lake Washington, and other large water bodies now occupy the major troughs.

Geologists generally agree that the Puget Sound area was subjected to six or more major glacial events, or glaciations, during the last 2 million years. The glacial ice for these glaciations originated in the coastal mountains of Canada and generally flowed southward into the Puget Sound region. The maximum southward advance of the ice was about halfway between Olympia and Centralia (about 50 miles south of Seattle). During the most recent glaciation, the ice is estimated to have been about 3,000 feet thick in the study area.

The sediment distribution in the Puget Sound area is complex as a result of the repeated glaciations. Each glaciation deposited new sediments and partially eroded previous sediments. During the intervening periods when glacial ice was not present, normal stream processes, wave action, and landsliding eroded and reworked some of the glacially derived sediments, further complicating the geologic setting as it is seen today. In the study area, the unconsolidated glacial and interglacial soils (soils deposited in between glacial events) are exceptionally thick. Borings and geophysical surveys indicate that approximately 1,300 to 3,500 feet of sediment overlie the bedrock in this area (Yount et al. 1985).

Bedrock is exposed at the surface in only a few locations in the Seattle area: Alki Point in West Seattle, the Duwamish Valley near Boeing Field, the southern portion of Rainier Valley, and Seward Park in southeastern Seattle. These bedrock exposures all occur south of an east-west line extending from the south end of Lake Sammamish on the east to Bremerton on the west. These bedrock exposures are coincident with the Seattle Fault Zone (see Exhibit 4-1 for the approximate location of surface splays in the project area), which consists of several subparallel faults that converge at depth to a single master fault. North of the Seattle Fault, the bedrock is deeply buried by glacial and nonglacial sediments.

4.2 Tectonics and Seismicity

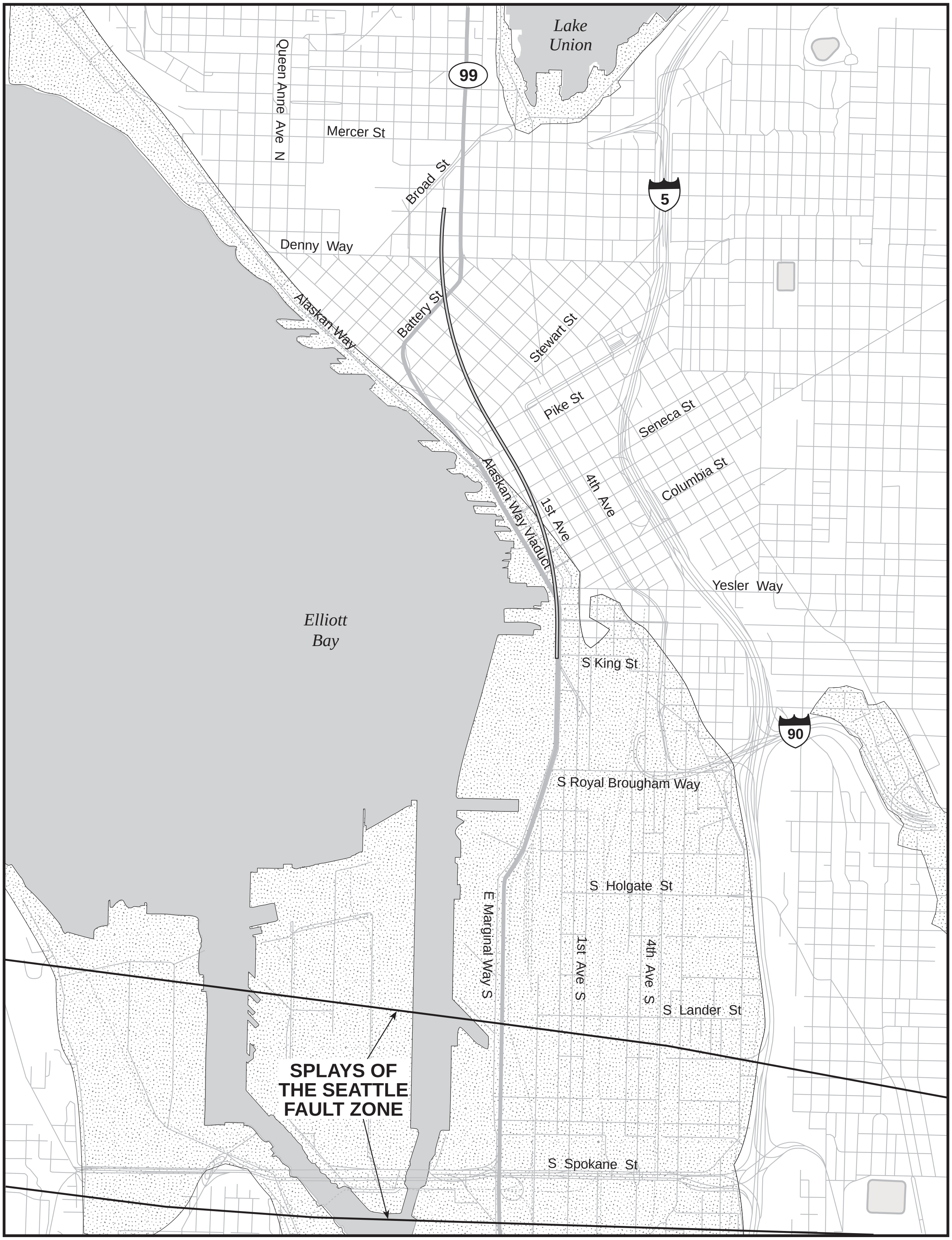
The study area is located in a region where numerous small to moderate earthquakes and occasional strong shocks have occurred in recorded history. Much of this seismicity is the result of ongoing relative movement and collision between the tectonic plates that underlie North America and the Pacific Ocean. These tectonic plates include the Juan de Fuca Plate and the North American Plate, and the intersection of these two plates is called the Cascadia Subduction Zone. As these two plates collide, the Juan de Fuca Plate is being driven northeast, beneath the North American Plate. The action of one plate being driven below another is called subduction. The relative movements of these plates are schematically shown on Exhibit 4-2.

The relative plate movements result not only in east-west compression, but also in shearing, clockwise rotation, and north-south compression of the crustal blocks that form the leading edge of the North American Plate (Wells et al. 1998). It is estimated that the compression rate for these blocks is about 0.03 to 0.04 inch per year, and much of the compression may be occurring within the more fractured, northern Washington block that underlies the Puget Lowland.

Within the present understanding of the regional tectonic framework and historical seismicity, three broad earthquake source zones are identified. These include a shallow crustal source zone, a deep source zone within the portion of the Juan de Fuca Plate subducted beneath the North American Plate (deep subcrustal zone), and an interplate zone where the Juan de Fuca and North American Plates are in contact in the Cascadia Subduction Zone. Two of these zones, the shallow crustal zone and the deep subcrustal zone, have produced the region's historical seismic activity.

4.2.1 Shallow Crustal Zone

The majority of historical earthquakes have occurred within the shallow crustal zone at depths of about 12 miles or less. With the exception of the 1872 North Cascades earthquake, all historical shallow crustal earthquakes have not been greater than magnitude 5.75. The North Cascades earthquake of December 15, 1872, is the largest historical shallow crustal earthquake to have occurred in Washington and is estimated to have been around magnitude ±7 (Malone and Bor 1979; Bakun et al. 2002). The fault on which this earthquake occurred has not been found, but is likely in the area around the southeast end of Lake Chelan.



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References: Seattle Fault Splays, Johnson (1999), Liquefaction areas, City of Seattle (2002).

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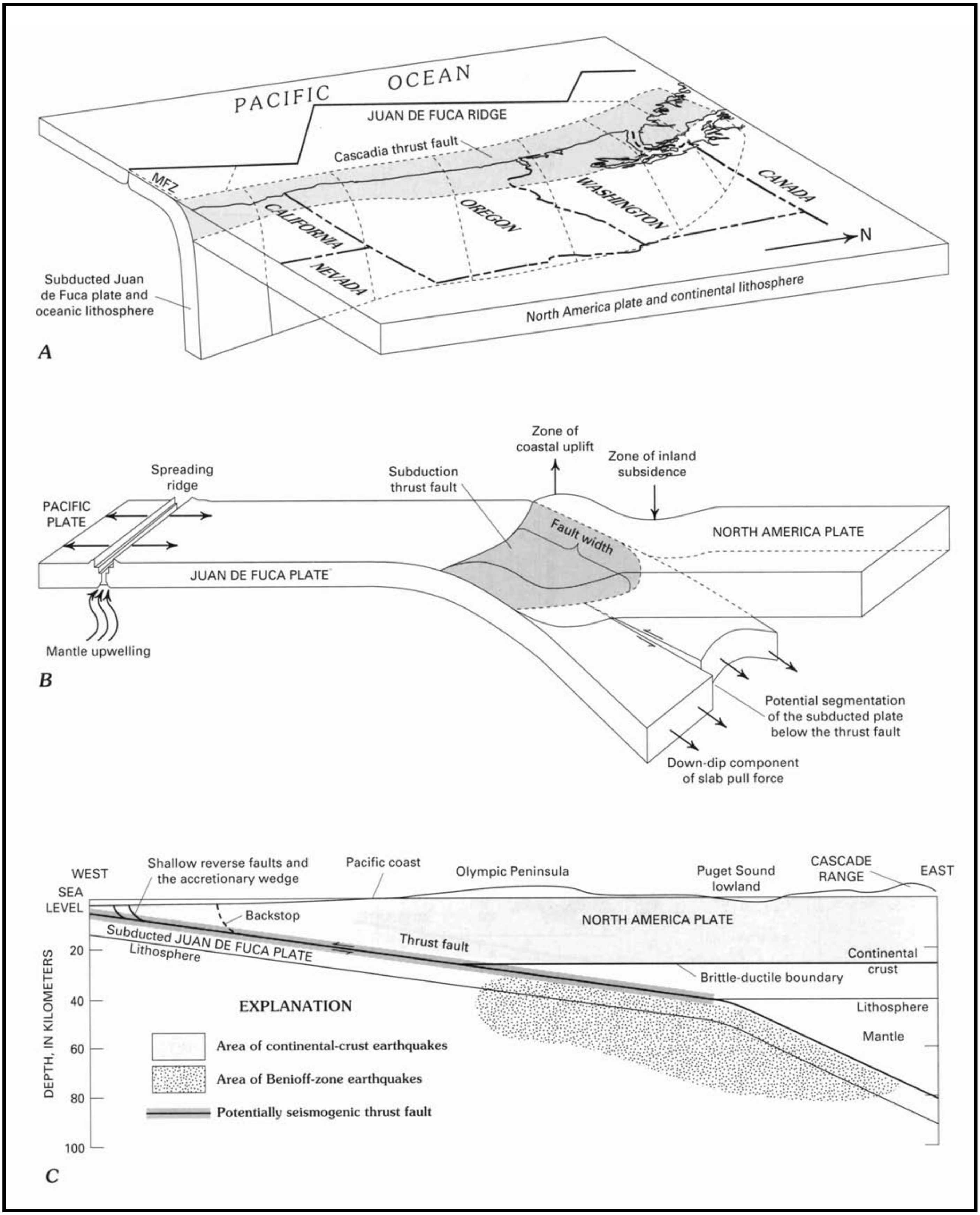
Liquefaction Areas

Tunnel Alignment

Exhibit 4-1
Mapped Liquefaction Areas and Seattle Fault Zone



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Source: Shannon & Wilson, Inc.

Exhibit 4-2
Schematic of the
Cascadia Subduction Zone

Along crustal faults identified by geologists in western Washington, shallow crustal earthquakes have not typically occurred in historical times (about the past 170 years). Until the late 1980s, it had generally been accepted that shallow crustal events within Puget Sound would be relatively small and limited to a maximum magnitude of about 6.0. However, geologic evidence developed during the 1990s indicates that the previously identified geophysical lineaments in western Washington are capable of producing earthquakes with magnitudes up to 7.5.

The closest crustal geophysical lineament to the site is the Seattle Fault (or Seattle Fault Zone). The Seattle Fault is believed to be a thrust or reverse fault, with the bedrock south of the fault being shoved up and over the bedrock and soil to the north of the fault. Within a few miles of the ground surface, the fault breaks up, creating a number of rupture surfaces or splays at the ground surface. The rupture zone at the ground surface is approximately 2 to 4 miles wide, north to south (Johnson et al. 1999). The fault zone extends from the Kitsap Peninsula near Bremerton on the west to the Sammamish Plateau on the east. In downtown Seattle, the locations of fault splays that rupture the ground surface are not well known. The approximate location of the two northernmost splays mapped within the study area is shown on Exhibit 4-1. Some current fault models suggest that the main fault (as opposed to the splays) does not extend to the ground surface near Seattle but extends farther north and is buried a few miles below the ground surface beneath downtown Seattle.

While no large historical earthquakes have occurred in the Seattle Fault Zone, geologic studies have shown that it is an active fault, with the most recent large event (estimated at magnitude 7) occurring approximately 1,100 years ago (e.g., Atwater and Moore 1992; Bucknam et al. 1992; Jacoby et al. 1992; Karlin and Abella 1992; Schuster et al. 1992; Pratt et al. 1997; Johnson et al. 1999; Brocher et al. 2001).

4.2.2 Deep Subcrustal Zone in the Juan de Fuca Plate

The largest historical earthquakes to affect the study area were located in the subducted Juan de Fuca Plate (deep subcrustal zone) at depths of 32 miles or greater. These events include the magnitude 7.1 earthquake of April 13, 1949, the magnitude 6.5 Seattle-Tacoma earthquake of April 29, 1965, and the recent magnitude 6.8 Nisqually earthquake of February 28, 2001. Earthquakes generated from the intraslab zone are likely caused by deformation and breakup of the subducting Juan de Fuca Plate beneath the North American Plate.

4.2.3 Interplate Zone

Within the Cascadia Subduction Zone, the interface between the Juan de Fuca Plate and the North American Plate has been identified as capable of producing very large interplate earthquakes. The interplate source is identified as the "subduction thrust fault" on Exhibit 4-2. No large interplate earthquakes have occurred in this zone during recorded historical times (about the past 170 years). However, an earthquake-generated tsunami that hit Japan in the year 1700 is believed to have been generated from a magnitude 9 earthquake in the Cascadia Subduction Zone (Satake et al. 1996). Recent geologic evidence suggests that the coastal estuaries have experienced rapid subsidence at various times within the last 2,000 years and that this subsidence may have been the result of a large earthquake that occurred at the Cascadia Subduction Zone interface (e.g., Atwater 1987, 1992; Grant 1989; Darienzo and Peterson 1990; Clarke and Carver 1992; Atwater and Hemphill-Haley 1997). Other evidence of large earthquakes within the Cascadia Subduction Zone includes the following:

- The presence of submarine landslide deposits in deep-sea channels off the coast of Washington and Oregon (Adams 1996).
- The presence of buried soils at Humboldt Bay (Clarke and Carver 1992) and in northern Oregon (Darienzo and Peterson 1995; Peterson and Darienzo 1996).
- Interbedded peat and mud at Coos Bay, Oregon (Nelson et al. 1996).
- Buried scarps near Willapa Bay (Meyers et al. 1996).
- Buried soils at Grays Harbor (Shennan et al. 1996).

Taken together, these different observations represent strong evidence that the Cascadia Subduction Zone has produced, and remains capable of producing, strong earthquakes. Work to date suggests that earthquake magnitudes may range from 8.0 to 9.0 and may occur at time intervals ranging from 400 to 1,000 years.

4.3 Site Geology

The study area is situated in the Seattle Basin, which is filled with over 1,500 feet of glacial and nonglacial sediments overlying bedrock. Glacial deposits are those that are deposited by the action of glaciers. Nonglacial deposits are those that are deposited when glaciers are not present, such as through natural water flow processes, landsliding, and wave action. Many of the glacial and nonglacial sediments have been glacially overridden, which means that the soils were compacted by the overriding weight of glacial ice as the glaciers advanced through the region. These glacially overridden soils are present in the subsurface below downtown Seattle and also underlie the younger, relatively loose and soft, postglacial soils that were deposited along the waterfront and Duwamish River delta. The geology in Seattle was further modified in the 1800s and early 1900s when portions of the city were regraded. Soil removed from the upper hills was transported to the low areas of Seattle along the waterfront and the tidelands south of Yesler Way.

Geologic maps of the surface geology (which does not include surficial geologic units less than about 5 feet thick) in the study area are shown on Exhibits 4-3 through 4-5.

These geologic maps are a surficial representation of subsurface conditions, and they were produced from many different sources of highly variable quality. Therefore, all the contacts are approximate, and the conditions depicted on the map and the actual conditions may vary. A summary description of the geologic units used on the map and in portions of this discussion is presented in Exhibit 4-6.

A map showing the elevation of the top of the glacially overridden soils in the study area is presented on Exhibit 4-7. The glacially overridden deposits are overlain by a thick sequence of very loose to dense or very soft to very stiff soils in the Duwamish delta and to the north along the waterfront. These materials were deposited after the retreat of the last glacier in the Seattle area and include beach, alluvial, estuarine, landslide, and fill deposits. These deposits are at least 250 feet thick south of S. Holgate Street and are found to depths of 30 to 50 feet north of S. King Street.

To facilitate the description of the affected environment, the study area has been divided into five areas:

- South Portal Area (S. Royal Brougham Way to S. King Street): thick fill and postglacial alluvial and estuarine deposits overlie glacially overridden sand and gravel deposits (soils that were compacted by the weight of overriding glacial ice).
- Bored Tunnel (S. King Street to Thomas Street): a thick, glacially overridden sequence of cohesive clay and silt interbedded with sand and gravel with varying amounts of silt exists along the bored tunnel alignment north to approximately Blanchard Street. From Blanchard Street to the north portal of the bored tunnel, a variable sequence of glacially overridden, clean to silty sand and gravel soils is present.
- North Portal Area (Thomas Street to Mercer Street): a thick sequence of coarse-grained alluvial deposits interspersed with thin, discontinuous layers of fine-grained soils is present.
- Elliott Bay Seawall and Waterfront (S. King Street to Stewart Street): a thick sequence of coarse-grained alluvial deposits interspersed with thin, discontinuous layers of fine-grained soils is present.
- Elliott/Western Connector (Pike Street to Battery Street): highly variable sequences of fine- and coarse-grained glacially overridden soils are present.

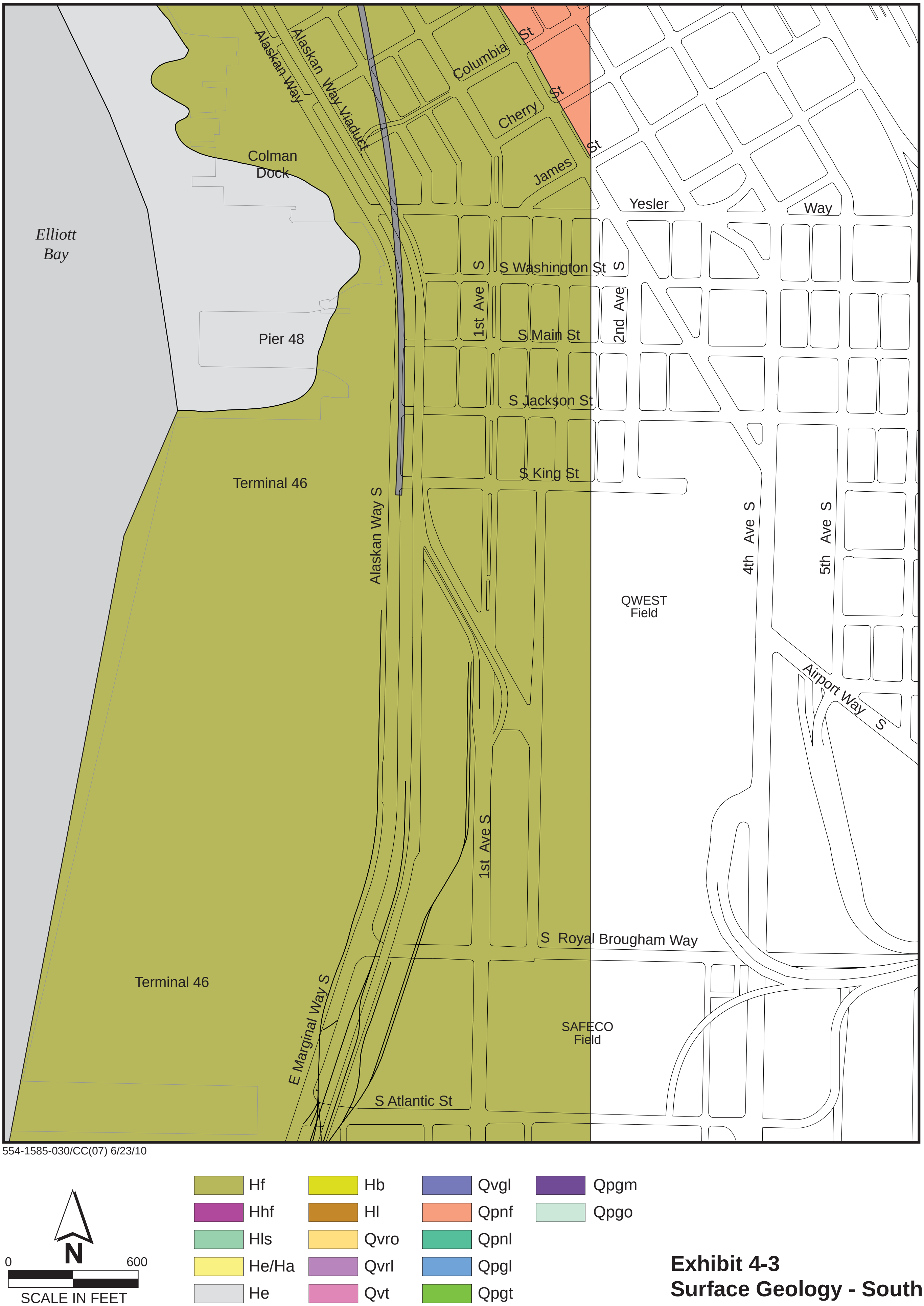
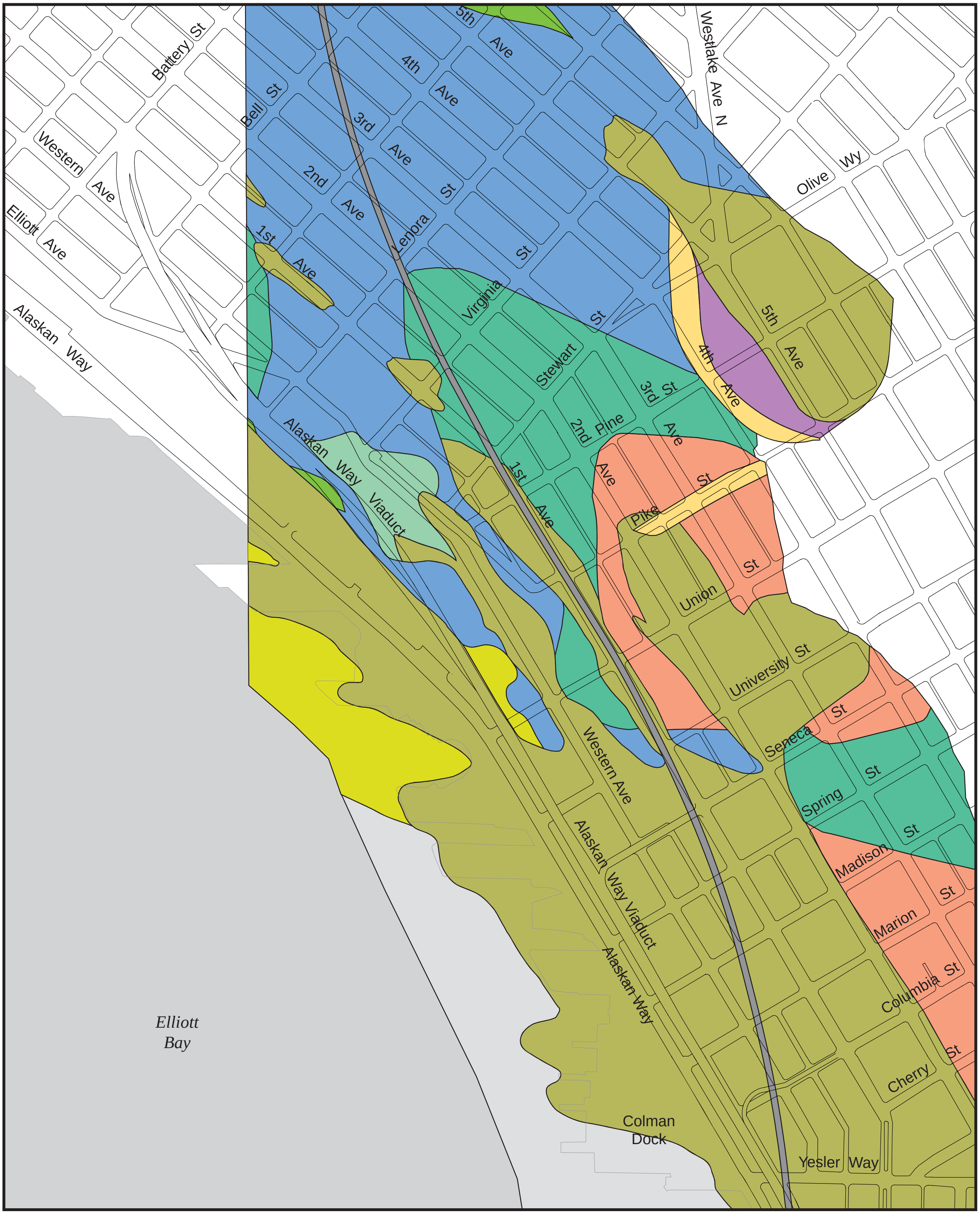


Exhibit 4-3
Surface Geology - South



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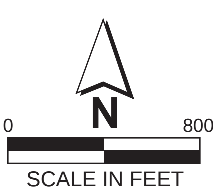

Hf	Hb	Qvgl	Qpgm
Hhf	Hl	Qpnf	Qpgo
Hls	Qvro	Qpnl	
He/Ha	Qvrl	Qpgl	
He	Qvt	Qpgt	

Exhibit 4-4
Surface Geology - Central

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Hf	Hb	Qvgl	Qpgm
Hhf	Hl	Qpnf	Qpgo
Hls	Qvro	Qpnl	
He/Ha	Qvrl	Qpgl	
He	Qvt	Qpgt	

N

0 600

SCALE IN FEET

Exhibit 4-5
Surface Geology - North

Exhibit 4-6. Geologic Units and Descriptions

Unit Name	Abbrev.	Unit Description[1]
HOLOCENE UNITS		
Fill	Hf	Fill, both engineered and nonengineered[2], placed by humans. Various materials, including debris (timbers, sawdust, coal slag, timber piles, railroad construction debris, and other materials); cobbles and boulders common; commonly dense or stiff if engineered, but very loose to dense or very soft to stiff if nonengineered.
Hydraulic Fill	Hhf	Fill placed by dredging from river or bay or sluiced into place from adjacent hills. Clay and silt, very soft to medium stiff (from hills); silt and fine sand; scattered shells; very loose to medium dense (not from hills).
Landslide Deposits	Hls	Deposits of landslides, normally at and adjacent to the toe of slopes. Disturbed, heterogeneous mixture of several soil types; loose or soft, with random dense or hard pockets.
Lacustrine Deposits	Hl	Depression filling of fine-grained soils. Silt; clayey silt; silty clay; clay; commonly scattered organics; very soft to stiff or very loose to medium dense.
Alluvium	Ha	River or creek deposits, normally associated with historical streams, including overbank deposits. Sand, silty sand, gravelly sand; very loose to very dense.
Peat Deposits	Hp	Depression fillings of organic materials. Peat, peaty silt, organic silt; very soft to medium stiff.
Estuarine Deposits	He	Estuary deposits of the ancestral Duwamish River. Silty clay and fine sand; very soft to stiff or loose to dense.
Beach Deposits	Hb	Deposits along present and former shorelines of Puget Sound and tributary river mouths. Silty sand, sandy gravel; sand; scattered fine gravel, organic and shell debris; loose to very dense.
Reworked Glacial Deposits	Hrw	Glacially deposited soils that have been reworked by fluvial or wave action. Heterogeneous mixture of several soil types; lies over glacially overridden soils; loose to dense.
VASHON UNITS		
Ice-Contact Deposits	Qvri	Heterogeneous soils deposited against or adjacent to ice during the wasting of glacial ice; commonly reworked. Stratified to irregular bodies of gravel, sand, silt, and clay; loose to very dense, or soft to hard.

Exhibit 4-6. Geologic Units and Descriptions (continued)

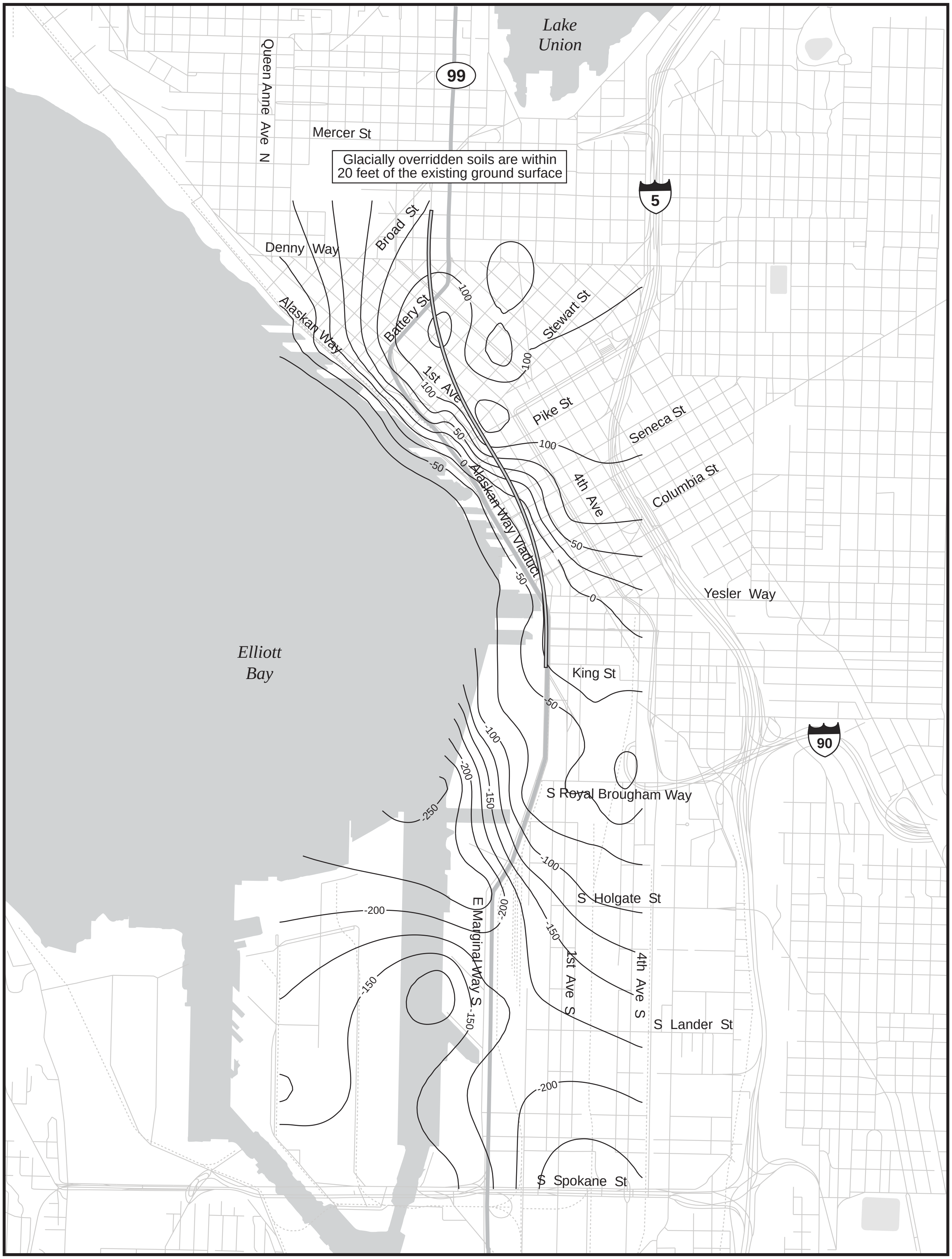
Unit Name	Abbrev.	Unit Description[1]
Recessional Outwash	Qvro	Glaciofluvial sediment deposited as glacial ice retreated. Clean to silty sand, gravelly sand, sandy gravel; cobbles and boulders common; loose to very dense.
Recessional Lacustrine Deposits	Qvrl	Glaciolacustrine sediment deposited as glacial ice retreated. Fine sand, silt, and clay; dense to very dense, soft to hard.
Till	Qvt	Lodgment till laid down along the base of the glacial ice. Gravelly silty sand, silty gravelly sand (hardpan); cobbles and boulders common; very dense.
Ablation Till	Qvat	Heterogeneous soils deposited during wasting of glacial ice; generally not reworked. Gravelly silty sand, silty gravelly sand, with some clay; cobbles and boulders common; loose to very dense.
Till-like Deposits (Diamict)	Qvd	Glacial deposit intermediate between till and outwash, subglacially reworked. Silty gravelly sand, silty sand, sandy gravel; highly variable over short distances; cobbles and boulders common; dense to very dense.
Advance Outwash	Qva	Glaciofluvial sediment deposited as the glacial ice advanced through the Puget Lowland. Clean to silty sand, gravelly sand, sandy gravel; dense to very dense.
Glaciolacustrine Deposits	Qvgl	Fine-grained glacial flour deposited in proglacial lake in Puget Lowland. Silty clay, clayey silt with interbeds of silt and fine sand; locally laminated; scattered organic fragments near base; hard or dense to very dense.
PRE-VASHON UNITS		
NONGLACIAL		
Fluvial Deposits	Qpnf	Alluvial deposits of rivers and creeks. Clean to silty sand, gravelly sand, sandy gravel, locally slightly clayey to clayey (weathered); scattered organics; very dense.
Lacustrine Deposits	Qpnl	Fine-grained lake deposits in depressions, large and small. Fine sandy silt, silty fine sand, and clayey silt; scattered to abundant fine organics; dense to very dense or very stiff to hard.
Mudflow Deposits	Qpnm	Distal deposits of mass movements such as landslides or lahars. Stratified or irregular bodies of a heterogeneous mixture of gravel, sand, silt, and clay; pumice, obsidian, and ash common; rare organics (charcoal); very stiff to hard or very dense.

Exhibit 4-6. Geologic Units and Descriptions (continued)

Unit Name	Abbrev.	Unit Description[1]
Peat Deposits	Qpnp	Depression fillings of organic materials. Peat, peaty silt, organic silt, hard.
Paleosol	Qpns	Buried, weathered horizon. Clay rich with various amounts of clastic debris; commonly contains organic material; typically greenish in color; hard or very dense.
Landslide Deposits	Qpls	Heterogeneous deposits of landslide debris. Chaotically bedded silt, sand, clay, and gravel; may contain wood and other organics; hard or very dense.
GLACIAL		
Outwash	Qpgo	Glaciofluvial sediment deposited as the glacial ice advanced through the Puget Lowland. Clean to silty sand, gravelly sand, sandy gravel; very dense.
Glaciolacustrine Deposits	Qpgl	Fine-grained glacial flour deposited in proglacial lake in Puget Lowland. Silty clay, clayey silt with interbeds of silt and fine sand; very stiff to hard or very dense.
Till	Qpgt	Lodgment till laid down along the base of the glacial ice. Gravelly silty sand, silty gravelly sand (hardpan); cobbles and boulders common; very dense.
Till-like Deposits (Diamict)	Qpgd	Glacial deposit intermediate between till and outwash, subglacially reworked. Silty gravelly sand, silty sand, sandy gravel; highly variable over short distances; cobbles and boulders common; very dense.
Glaciomarine Deposits	Qpgm	Till-like deposit with clayey matrix deposited in proglacial lake by icebergs, floating ice, and gravity currents. Heterogeneous and variable mixture of clay, silt, sand, and gravel; rare shells; cobbles and boulders common; very dense or hard.

Notes:

1. The geologic units are interpretive and based on the project team's opinion of the grouping of complex sediments and soil types into units appropriate for the Program. The description of each geologic unit includes only general information regarding the environment of deposition and basic soil characteristics. For example, cobbles and boulders are included only in the description of units in which they are most prominent.
2. Engineered fill assumes quality control during placement using specified compaction criteria, including field density testing, select fill materials, moisture conditioning, appropriate compaction equipment, and proper compactive effort. Nonengineered fill is typically loosely dumped or hydraulically placed with little or no quality control.



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N

0 2,500

SCALE IN FEET

Tunnel Alignment

-150 Contours Represent Elevation

Note: Elevation Datum is NAVD88

Exhibit 4-7
Elevation of Top of Glacially Overridden Soil

Exhibit 4-8 shows a generalized subsurface profile along the alignment of the bored tunnel and south and north portal areas. This exhibit depicts three generalized soil groups:

- Recent Sand and Silt: this group includes all of the soil deposits that have not been glacially overridden (Hf, Ha, He, Hl, Hb, Hrw, Qvro, Qvri, Qvrl, and Qvat).
- Glacial Clay and Silt: this group includes glacially overridden, fine-grained deposits that have various amounts of clay (Qpnf, Qpnl, and Qpgl). Some of these deposits also include fine sand.
- Glacial Sand, Gravel, and Silt: this group includes glacially overridden sand and gravel deposits (Qpnf and Qpgo) and till-like deposits (Qvt, Qvd, Qpgt, Qpgl, Qpgm, Qpnf, and Qpns).

4.3.1 South Portal Area – S. Royal Brougham Way to S. King Street

Approximately 30 to 90 feet of recent sand and silt deposits overlie glacially overridden sand, gravel, and silt along the south portal area. The recent sand and silt soils consist of fill soils of variable compositions (Hf), sandy alluvium deposited by the Duwamish River (Ha), silt and fine sand estuarine deposits (He), and sandy beach soils (Hb). These soils were deposited after the retreat of glacial ice in Puget Sound and are not glacially overridden.

Below the recent deposits, glacially overridden sand, gravel, and silt extend to the depths of the existing subsurface explorations. The layer of glacially overridden silt, sand, and gravel is approximately 80 to 100 feet thick and consists of 20- to 30-foot-thick glacial till (Qpgt) layers interbedded with less silty, water-lain sand and gravel (Qpgo and Qpnf). A 20- to 25-foot-thick cohesive layer of clay and silt (Qpgl and Qpnl) underlies the glacially overridden silt, sand, and gravel near S. Royal Brougham Way. Northward near S. King Street, 10- to 50-foot-thick clay and silt layers are interbedded with 20- to 30-foot-thick glacially overridden silt, sand, and gravel layers.

The fill deposits (Hf) in the south portal area contain large amounts of wood and debris. The wood debris consists of horizontal and vertical timbers and piles, mill ends, sawdust, and wood chips. The depth and extent of the wood debris varies along the alignment. Based on historical information, the northern half of the south portal area is located near the former site of a large sawmill (Yesler's Mill). It is likely that large deposits of floating wood, piles for pier structures, and wood debris were present in this area before fill was placed in the area circa 1900. This wood deposit was also noted in the excavation performed in 2008 for the 505 First Avenue S. Building adjacent to the north end of the Railroad Avenue ramps to the existing viaduct (Shannon & Wilson 2008b).

Generalized Subsurface Profile

ALONG BORED TUNNEL ALIGNMENT

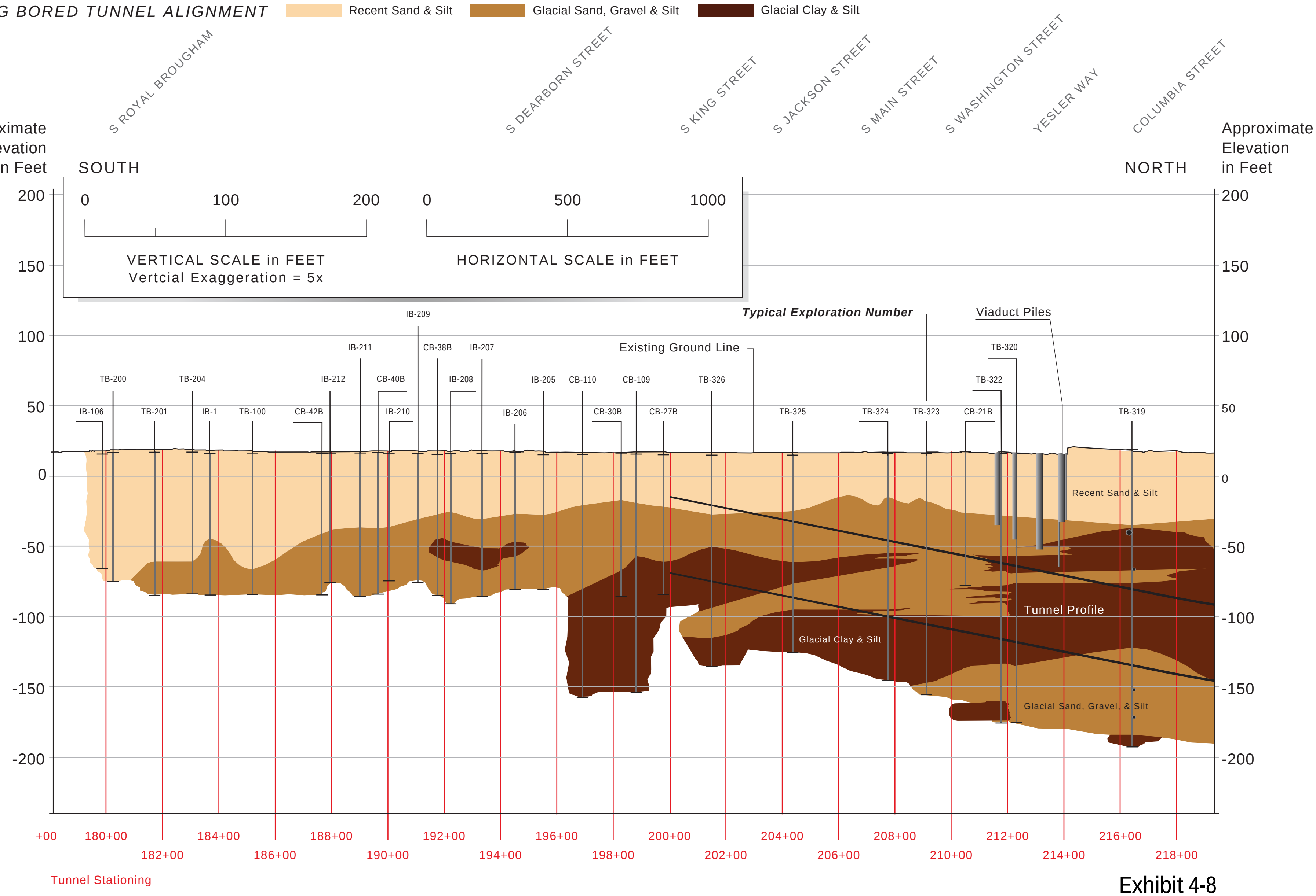

Exhibit 4-8

Generalized Subsurface Profile

ALONG BORED TUNNEL ALIGNMENT

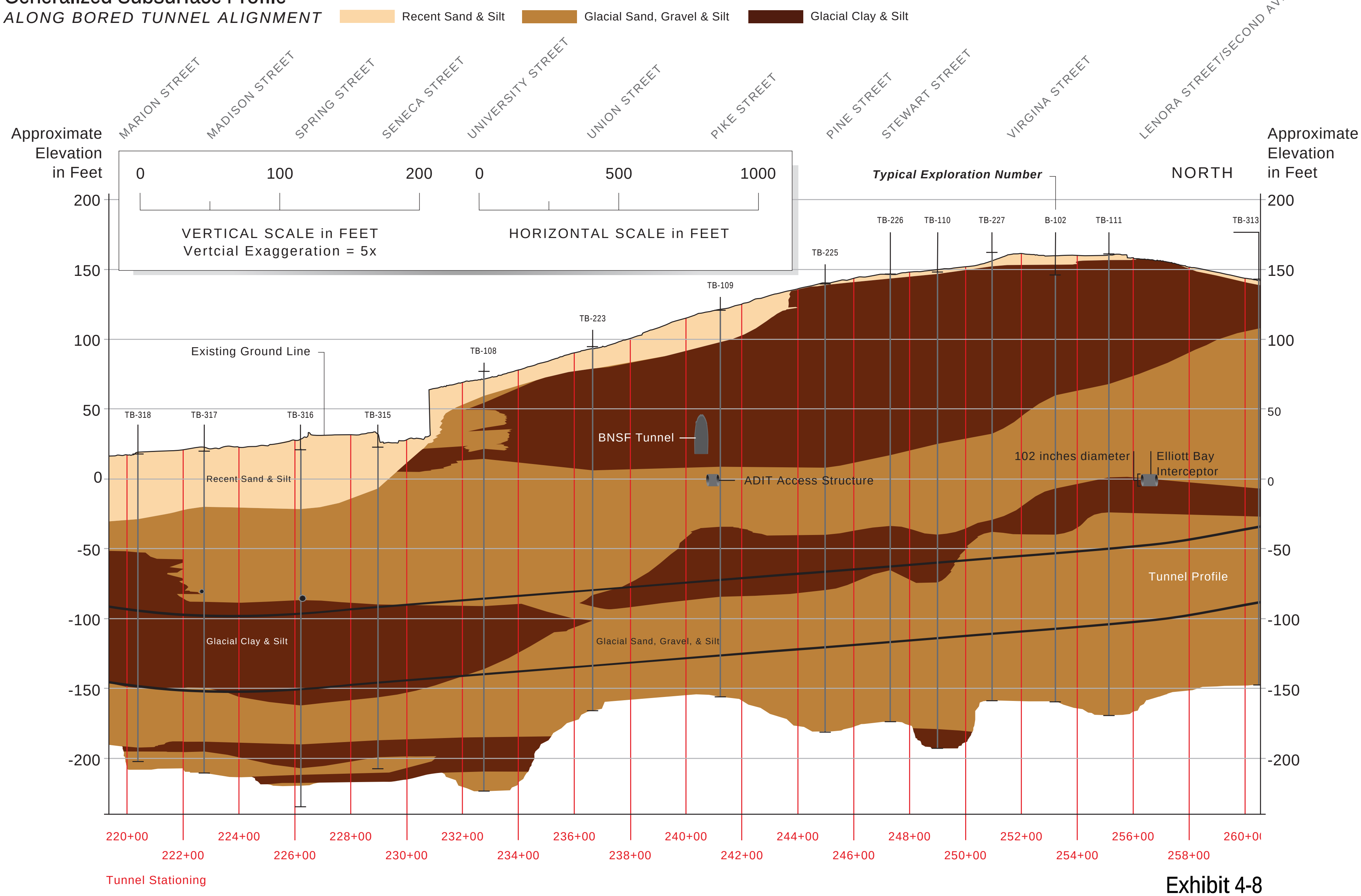

Exhibit 4-8

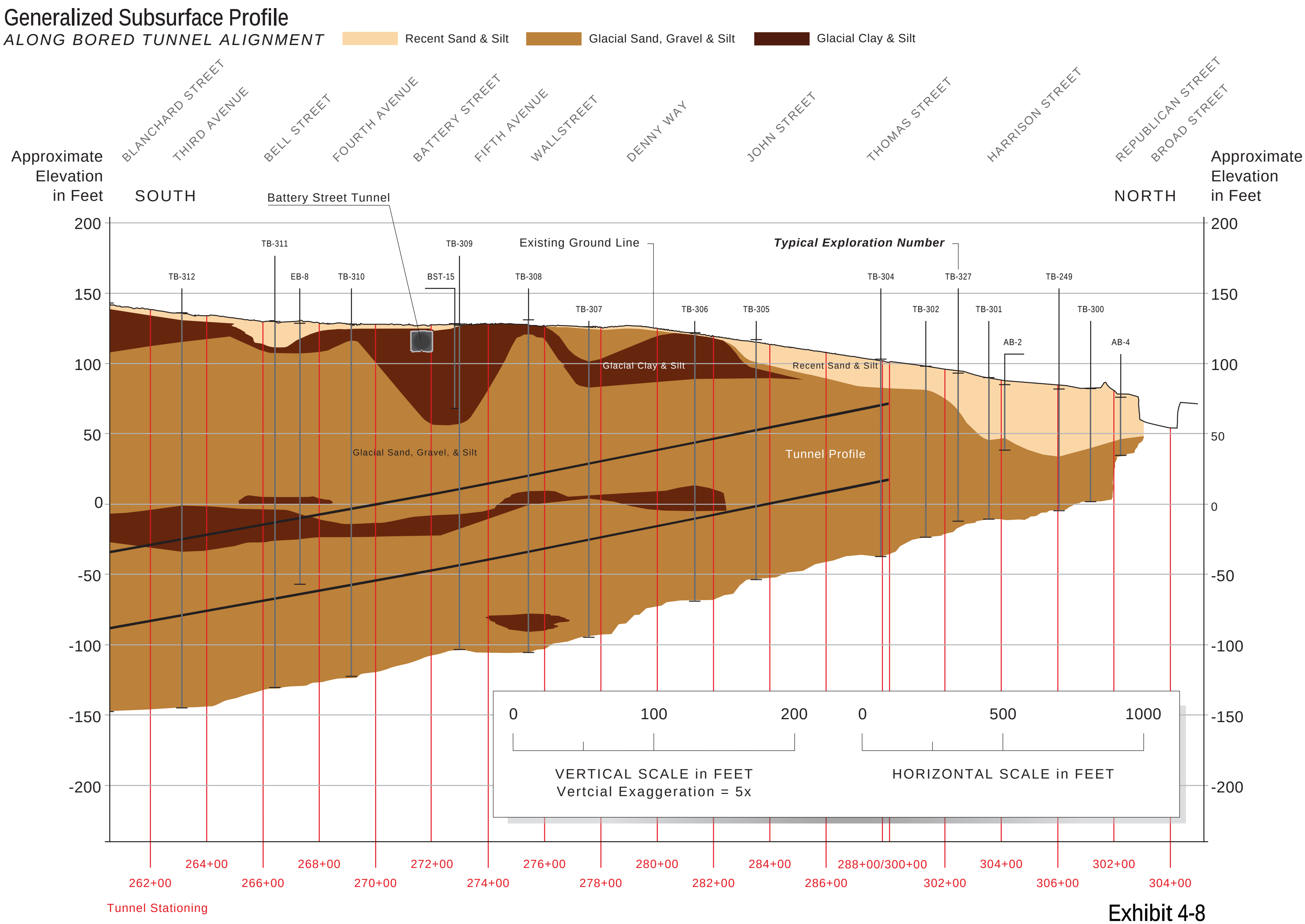
Generalized Subsurface Profile
ALONG BORED TUNNEL ALIGNMENT
Recent Sand & Silt
Glacial Sand, Gravel & Silt
Glacial Clay & Silt
BLANCHARD STREET
THIRD AVENUE
BELL STREET
FOURTH AVENUE
BATTERY STREET
FIFTH AVENUE
WALLSTREET
DENNY WAY
JOHN STREET
THOMAS STREET
HARRISON STREET
REPUBLICAN STREET
BROAD STREET
Approximate Elevation in Feet
SOUTH
NORTH
Battery Street Tunnel
Existing Ground Line
Typical Exploration Number
TB-312
TB-311
EB-8
TB-310
BST-15
TB-309
TB-308
TB-307
TB-306
TB-305
TB-304
TB-302
TB-327
TB-301
AB-2
TB-249
TB-300
AB-4
Glacial Clay & Silt
Recent Sand & Silt
Glacial Sand, Gravel, & Silt
Tunnel Profile
200
150
100
50
0
-50
-100
-150
-200
VERTICAL SCALE in FEET
Vertcial Exaggeration = 5x
HORIZONTAL SCALE in FEET
0 100 200
0 500 1000
262+00
264+00
266+00
268+00
270+00
272+00
274+00
276+00
278+00
280+00
282+00
284+00
286+00
288+00/300+00
302+00
304+00
306+00
302+00
304+00
Tunnel Stationing

Exhibit 4-8

4.3.2 Bored Tunnel – S. King Street to Thomas Street

The bored tunnel would extend primarily through glacially overridden soil deposits. Between S. King Street and Yesler Way, the bored tunnel alignment is located west of the existing viaduct. In this area, the subsurface conditions consist of approximately 30 to 40 feet of recent sand, gravel, and silt deposits overlying glacially overridden soils. The recent deposits consist of fill soils of various compositions, fine-grained estuarine soils, and sand and gravel soils deposited by water melting off the glacial ice as the glacier retreated to the north. These soils have not been overridden by glacial ice and are typically loose to dense or soft to very stiff. The fill soils near Yesler Way contain wood debris layers up to 20 feet thick. The glacially overridden deposits underlying the recent deposits in this area consist primarily of very dense till and till-like sand and gravel.

North of Yesler Way, the bored tunnel extends beneath downtown Seattle at depths of more than 100 feet below the ground surface. Since the construction of the bored tunnel would generally not affect the surficial earth environment in this area, the soil descriptions provided in this section are for the bored tunnel horizon (depth zone through which the tunnel would be bored) only. From about Yesler Way to Madison Street, the tunnel would extend primarily through very dense and hard fine-grained deposits (fine sand, silt, and clay) with some zones of sandy gravel. From about Madison Street to University Street, hard silt and clay deposits compose most of the tunnel horizon. From about University Street to Virginia Street, the lower portion of the tunnel horizon is located primarily through sand deposits, and the upper portion of the tunnel horizon is located in sand and silt deposits. North of Virginia Street, most of the soils along the tunnel horizon consist of very dense sand and gravel soils. In localized areas, thin layers (less than 20 feet thick) of silt and clay are present in the tunnel horizon.

North of Denny Way, the bored tunnel alignment extends beneath Sixth Avenue N. Along this section of the alignment, the thickness of the recent surficial deposits ranges from about 10 to 20 feet. The underlying glacially overridden soils primarily consist of very dense sand and gravel deposits, including Qpgt, Qpgd, and Qpgo.

4.3.3 North Portal Area – Thomas Street to Mercer Street

Recent deposits of sand and silt with varying amounts of clay are present in the north portal area. These deposits consist of fill overlying glacial silt, sand, and clay with varying amounts of gravel deposited during the retreat of glacial ice. The recent deposits extend to depths ranging between 15 and 50 feet below the ground surface and range in density or consistency from loose to dense or soft to very stiff, respectively.

Glacially overridden silt, sand, and gravel underlie the recent deposits and consist primarily of sand and gravel with varying amounts of silt, ranging from cohesionless sand and gravel south of Harrison Street to till and till-like deposits north of Harrison Street.

4.3.4 Other Program Elements

Elliott Bay Seawall and Waterfront – S. King Street to Stewart Street

The soil deposits along the waterfront are affected by the Duwamish River, Elliott Bay, and the hills of Seattle. Beach deposits in Elliott Bay were reworked and then overlain by alluvial deposits from the Duwamish River and landslide debris from higher ground to the east of the shoreline. In some areas, these deposits were also interbedded with each other (alternating thicknesses of beach, alluvial, and landslide deposits).

Fill deposits are present to depths of 10 to 40 feet along the waterfront. A large volume of fill material exists near Pier 66 between Broad and Lenora Streets. This material was reportedly placed in this area during the historical Belltown/Denny Regrade project in the early twentieth century. Much of the shallow soil along the southern portion of the waterfront was soil that was dredged from the Duwamish Waterway and hydraulically placed (placed using water). The fill locally contains scattered to abundant wood debris, including creosote-treated piles (vertical grain), driftwood (cross-grain), and sawdust (up to 20 feet thick). Brick, porcelain, concrete, asphalt, and other construction debris have also been encountered within the fill deposits along the waterfront.

In addition to the fill deposits, other recent native deposits extend to depths of about 20 to 80 feet below the ground surface. The underlying glacially overridden soils generally consist of cohesive silt and clay interbedded with granular deposits of sand and gravel.

Elliott/Western Connector – Pike Street to Battery Street

On the hillside east of the waterfront area and south of Seattle Center, a complex series of glacially overridden soils are present. Near the base of the hill, recent deposits typically consist of fill deposits and recessional soil deposits after the glaciers receded (not overridden). Very dense or very stiff to hard, glacially overridden soils are located at depths ranging from as much as 45 feet below the ground surface near the base of the hill to only a few feet below the ground surface in the upland areas.

4.4 Geologic Hazards

Geologically hazardous areas are defined as areas that—because of their susceptibility to erosion, landslides, earthquakes (faulting, liquefaction, ground shaking, etc.), or other geologic events—are not suited for development consistent with public health and safety concerns. Washington State's Growth Management Act (Revised Code of Washington, Chapter 36.70A) requires all cities and counties to identify geologically hazardous areas within their jurisdictions and formulate development regulations for their protection.

The City of Seattle has developed regulations for environmentally critical areas and associated maps (Seattle 2002). These regulations require that detailed geotechnical studies be prepared to address specific standards relating to site geology and soils, seismic hazards, and facility design. The following sections summarize the types of geologic hazards that may be expected within the study area. Many of these hazards are interrelated.

4.4.1 Landslides

The City of Seattle has identified landslide-prone areas that include steep slopes, known landslide areas, and areas with landslide potential because of geologic conditions. Steep slopes are defined by the City of Seattle as slopes steeper than an average of 40 percent and with at least 10 feet of vertical change. Steep slopes are present on the eastern side of the BNSF railroad tracks, between Virginia and Bell Streets. The steeper parts of the slopes in this area range from about 50 to 100 percent. In the past few years, several small, shallow landslides have occurred on these slopes. They are typically 1 to 3 feet deep and are generally 10 to 30 feet wide. No recent deep-seated landslides have been observed in this area. During a seismic event, increased shallow landsliding may occur in this area.

Some of the slopes at the ground surface in downtown Seattle over the bored tunnel alignment may be classified as steep. However, because these areas are fully developed with buildings, roadways, and other structures, the potential for landslides in these areas is low.

4.4.2 Erosion

The study area is primarily classified as urban development and is therefore not an erosion hazard area. However, the steep slopes located along the eastern side of the BNSF railroad tracks between Virginia and Bell Streets have experienced surface erosion and gully development during conditions of substantial runoff.

4.4.3 Fault Rupture

The Program area is located near the Seattle Fault Zone. As described in Section 4.2.1, the fault breaks up within a few miles of the ground surface, creating a number of rupture surfaces or splays at the ground surface. The rupture zone at the ground surface is approximately 2 to 4 miles wide, north to south (Johnson et al. 1999). In downtown Seattle, the locations of fault splays that rupture the ground surface are not well known. Exhibit 4-1 shows the approximate location of the two northernmost splays mapped within the study area. Some current fault models suggest that the main fault (as opposed to the splays) does not extend to the ground surface near Seattle but extends farther north and is buried a few miles below the ground surface beneath downtown Seattle. However, with these models, the zone of surface deformation and rupture is believed to be near the mapped splays shown on Exhibit 4-1.

Geologic evidence gathered over the last 10 years suggests that surface rupture of this fault zone occurred as recently as 1,100 years ago, with as much as 22 feet of vertical displacement (Bucknam et al. 1992). Recent trenches excavated along the fault locations indicate that there have been about three events during which the surface was ruptured in the past 10,000 years (Nelson et al. 2000). On average, the recurrence interval over the last 16,000 years for large-magnitude events on the Seattle Fault appears to be about 3,000 to 5,000 years, with individual recurrence intervals ranging from as short as about 200 years to as long as 12,000 years (Johnson 2004). Also, fault splays in the northern portion of the zone appear to be the most recently active and capable of rupturing the ground surface, resulting in several feet of vertical offset.

Intense ground shaking in the direction of the fault rupture at sites located within a few miles of the fault is another effect of fault rupture. The intense ground shaking "pulses" or directivity effects is the result of constructive wave interference in the direction of the fault rupture.

4.4.4 Liquefaction

Soil liquefaction occurs in loose, saturated, sandy soil when the water pressure in the pore spaces increases to a level that is sufficient to separate the soil grains from each other. This phenomenon occurs during ground shaking and results in a reduction of the shear strength of the soil (a quicksand-like condition). The reduction in strength depends on the degree and extent of the liquefaction. Liquefaction can result in ground settlement, lateral spreading (lateral ground movement on gentle slopes), landsliding, localized ground disruptions from sand boils (ejection of sand and water at the ground surface), and reduced vertical and lateral capacity for structure foundations. Buildings, bridges, and other structures founded on or in the liquefied soils may settle, tilt, move laterally, or collapse. The degree of liquefaction depends on the consistency and density of the soil, the grain-size distribution of the soil, and the magnitude of the seismic event. Settlement could also result from partial liquefaction or densification of unsaturated sand.

Geologic units in the study area that typically have a high susceptibility to liquefaction if they are present below the water table include the recent alluvial and beach deposits and nonengineered fills. These deposits are primarily located in the southern portion of the study area and along the waterfront. Liquefaction studies in the Puget Sound region have found that glacially overridden deposits have a low susceptibility to liquefaction. Liquefaction hazard areas have been mapped by the City of Seattle (2002) and are shown on Exhibit 4-1. Liquefaction studies have also been accomplished using the results from available explorations and the borings completed for the Program. The results of these studies generally confirm the liquefaction areas shown on Exhibit 4-1.

4.4.5 Ground Motion Amplification

The presence of soil above bedrock can change the intensity of ground shaking felt at the ground surface compared to the intensity that would be felt if only bedrock were at the ground surface. Very soft or loose soils may cause the ground shaking to be amplified (greater than that felt on rock) or attenuated (less than that felt on rock). Ground motion amplification may result in higher-intensity ground motions felt by long bridges and similar long-period structures.

The soil conditions in the study area range from deep, loose, liquefiable deposits at the south end to deep, glacially overridden, sandy, silty, and gravelly soils at the north end. At the south end of the study area, the potential for ground motion amplification varies. For small or distant earthquakes that cause low intensities of shaking, the potentially liquefiable soils are likely to amplify the ground shaking. For large, nearby earthquakes that cause more intense shaking, little amplification or even attenuation of higher-frequency ground motions is possible before liquefaction would occur. However, for the same nearby earthquake, low-frequency ground motions at liquefiable sites are likely to be amplified.

4.4.6 Seiches and Tsunamis

Seiches and tsunamis are short-duration, earthquake-generated water waves. Seiches are waves that occur in enclosed bodies of water, and tsunamis are waves that occur in the open ocean. The extent and severity of these waves depend on ground motions, fault offset, and location. Results of studies of these types of waves in Puget Sound are presented on the Tsunami Hazard Map of the Elliott Bay Area (Walsh et al. 2003). These studies indicated that a magnitude 7.3 to 7.6 earthquake caused from a rupture of the Seattle Fault may result in a wave that would inundate much of the waterfront in excess of 6 feet. If this event occurs, most of the southern portion of the alignment (south of Marion Street) would be inundated. On average, the recurrence interval over the last 16,000 years for large-magnitude events on the Seattle Fault appears to be about 3,000 to 5,000 years, with individual recurrence intervals ranging from as short as about 200 years to as long as 12,000 years (Johnson 2004).

Tsunamis generated from large earthquakes in the Pacific Ocean basin would also likely result in inundation of the waterfront and viaduct. Studies are currently ongoing, but several feet of inundation along the waterfront and viaduct corridor from a tsunami run-up would be likely. Historical data from the 1964 Alaska earthquake in Prince William Sound show a tsunami run-up of 0.8 foot (Wilson and Torum 1972).

4.5 Regional Groundwater Systems

The two main aquifer systems in the Seattle area are both glacially overridden alluvial deposits composed of coarse-grained sediments, such as sand and gravel that were deposited by glacially fed streams. The geologic unit of the upper aquifer is known as the Vashon Advance Outwash (Esperance Sand), and the geologic unit of the deeper aquifer is known as pre-Vashon Outwash (Qpgo). Both of these geologic units are widespread throughout the study area but are locally discontinuous.

Separating these aquifers are fine-grained soil deposits that do not readily transmit groundwater and therefore impede the vertical movement of groundwater between the two aquifers. These fine-grained layers, which are referred to as aquitards, include the geologic unit known as the Vashon Glaciolacustrine deposit (Lawton Clay), nonglacial lake deposits, and fine-grained sediments. As with the aquifer units, these aquitards are not necessarily continuous on an areawide basis, and where absent, the Vashon Advance Outwash and deeper pre-Vashon Outwash aquifers are in direct contact with each other.

In addition to the two main aquifers, several other near-surface geologic units may yield sufficient water for domestic use. Recent alluvial soils deposited by modern rivers and streams may be a local source of groundwater, depending on the thickness and permeability of the soils. In some areas of Puget Sound, glacial outwash soils that were deposited as the glaciers receded are sufficiently extensive to serve as aquifers. However, in the Seattle area, these units are generally thin and discontinuous; although these deposits may contain water, they generally are inadequate in extent and quality to be used for water supply. Hydraulic connection between the near-surface alluvial or glacial outwash deposits and the underlying aquifers is often limited by the presence of fine-grained deposits, including layers of clay and silt.

4.6 Regional Groundwater Flow

Groundwater flow in the Seattle area is generally controlled by the complex distribution of fine- and coarse-grained deposits, local topography, areas where precipitation provides recharge to aquifers, and areas where groundwater discharges. Groundwater recharge typically occurs in the upland areas of Seattle, including Capitol Hill, Queen Anne Hill, Magnolia Hill, and the University District. Groundwater movement from these recharge areas is predominantly downward toward the discharge areas, which are typically major surface water bodies such as Lake Union, Lake Washington, and Elliott Bay.

The direction of groundwater movement is also controlled in part by the ability of the soil to transmit water, which is called the hydraulic conductivity of the soil. In the upper part of the soil profile, groundwater flow in the coarse-grained deposits, such as Vashon Advance Outwash, is predominantly horizontal under water table conditions and may discharge at springs or seeps on the hillsides. The groundwater in these units is typically perched on top of fine-grained soils that do not readily transmit groundwater. Consequently, where fine-grained units are present, only a small portion of this groundwater is able to move vertically downward through the fine-grained units to the aquifer in the underlying coarse-grained sediments.

Groundwater flow in water-bearing units at and below sea level is primarily governed by the hydraulic gradient (difference in water levels) between groundwater and surface water discharge areas, including Lake Union, Lake Washington, and Elliott Bay. The hydraulic gradient determines the potential for groundwater to move in a particular direction, with groundwater moving from high water levels to low water levels. Inland of the surface water bodies listed above, the hydraulic gradients are typically downward. The surface water bodies are in turn discharge areas, with groundwater flow generally upward in their vicinity. In the Seattle area, Lake Union, Lake Washington, and Elliott Bay are regional groundwater discharge areas.

4.7 Site Groundwater Conditions

Groundwater conditions in the Program area are generally consistent with the regional groundwater systems. Groundwater conditions are to a large extent controlled by geologic soil conditions and the presence of Elliott Bay. Groundwater conditions for the five areas described in Section 4.3 are discussed in the following sections. Groundwater quality is described in Appendix Q, Hazardous Materials Discipline Report.

4.7.1 South Portal Area

The water table elevation in this area is essentially flat, with the depth to groundwater ranging from approximately 2 to 12 feet below the ground surface. According to groundwater measurements in existing monitoring wells, the water table fluctuates 2 feet or less due to tides. Water levels in the deeper soils are generally similar to the level of the water table, indicating that there is little to no vertical hydraulic gradient. The water table in the deeper soils appears to have a slightly higher sensitivity to tidal fluctuations.

The relative hydraulic conductivity of the soils overlying the glacially overridden deposits is generally low, with the exception of local zones of alluvial and beach sand deposits, which may have a higher hydraulic conductivity. The relative hydraulic conductivity of the glacially overridden soils is generally low, except for the coarse-grained sand and gravel deposits to the north, which have a relatively high hydraulic conductivity.

Groundwater flow in this area is generally horizontal toward Elliott Bay. Most of the groundwater flow occurs within the fill material, in the coarser-grained alluvial and beach deposits, and in the coarse-grained glacial soils to the north. Vertical movement of groundwater is limited by the lack of vertical gradient and the presence of silt and clay layers.

4.7.2 Bored Tunnel

Groundwater conditions along the south part of the tunnel (south of Yesler Way) are similar to those discussed for the south portal area in Section 4.7.1. North of Yesler Way, the water table along the bored tunnel alignment is at an elevation between about +10 and +20 feet. The water table is approximately 4 to 12 feet below the ground surface within the fill in the southern portion of the bored tunnel section and increases to the north to about 150 feet near Lenora Street because of the increase in the ground surface elevation. North of Lenora Street, the depth to the water table decreases as the ground surface elevation decreases, with a depth to the water table of about 70 to 80 feet near Thomas Street. North of Seneca Street, isolated zones of perched groundwater may be present in shallow soils. In some areas the groundwater level is higher than ground surface (i.e., groundwater would flow from an uncapped well), which is termed "artesian" conditions. These artesian groundwater conditions were encountered between about S. King Street and Madison Street and indicated water heads of as much as 5 feet above the ground surface.

Groundwater flow along the bored tunnel section occurs primarily in the coarse-grained sand and gravel layers that are confined by overlying fine-grained soils. In general, groundwater flow is horizontal toward Elliott Bay. In some areas, there is an upward hydraulic gradient as groundwater flows toward the Elliott Bay discharge area. However, the intervening layers of fine-grained soils slow the vertical movement of groundwater between layers.

Groundwater conditions along most of the bored tunnel alignment are highly variable due to the interlayering of fine- and coarse-grained soils. In general, coarse-grained sands and gravels are the primary water-bearing units in this area. Fine-grained sediments overlie these deposits. In some areas, small zones of shallow groundwater are perched on top of the fine-grained soils. Between and beneath these perched water-bearing zones, the fine-grained soils are generally unsaturated down to the underlying water table aquifer.

The relative hydraulic conductivity of the upland soils is low for the fine-grained deposits and high for the coarse-grained deposits. The horizontal hydraulic gradient is generally to the west toward Elliott Bay. The direction of flow for shallow, perched groundwater is locally controlled by the geometry and extent of the soils on which the water is perched and the near-surface topography.

4.7.3 North Portal Area

This area is underlain by interlayered fine- and coarse-grained soils. In general, coarse-grained sands and gravels are the primary water-bearing units in this area. These deposits are generally overlain by fine-grained sediments. In some areas, small zones of shallow groundwater are perched on top of the fine-grained soils. Between and beneath these perched water-bearing zones, the fine-grained soils may be unsaturated down to the underlying water table aquifer, particularly at the south end of this area.

The depth to groundwater is a function of ground surface elevation (see Exhibit 4-8) and the presence of perched water-bearing zones. Near Thomas Street, the regional water table is generally between 60 and 70 feet below the ground surface. To the north, the regional water table is shallower as the ground surface dips downward toward Lake Union.

The relative hydraulic conductivity is low for the fine-grained deposits and high for the coarse-grained deposits. Groundwater hydraulic gradients and flow directions have not been determined in this area; however, groundwater underlying the northern half of this area likely flows toward Lake Union. The direction of flow for shallow, perched groundwater is locally controlled by the geometry and extent of the soils on which it is perched and the near-surface topography.

4.7.4 Other Program Elements

Elliott Bay Seawall and Waterfront

Groundwater is encountered approximately 4 to 12 feet below the ground surface within the fill materials. The water table is relatively flat and appears to fluctuate in response to tidal action. The magnitude of the tidal fluctuation generally appears to be a function of the seawall type and its integrity. In contrast, groundwater levels measured in the deeper coarse-grained soils show a response to Elliott Bay tides, with fluctuations ranging from approximately 1 to 7 feet.

Within the fill adjacent to the seawall, the hydraulic conductivity is highly variable as a result of the heterogeneous nature of this deposit. The relative hydraulic conductivity of the glacially overridden deposits adjacent to the seawall is low for the fine-grained silt and high for the coarse-grained sand and gravel. In the northern half of the area, the upper zone of the coarse-grained sand and gravel, which contains a higher percentage of silt and clay, has a lower hydraulic conductivity than the underlying sand and gravel.

Groundwater flow is variable and dependent on the soil type. The flow occurs primarily in the coarse-grained sand and gravel layers, which are confined by the overlying fine-grained soils. In general, groundwater flow is horizontal toward Elliott Bay. Along most of this area, there is an upward hydraulic gradient as groundwater flows to the Elliott Bay discharge area. However, the intervening layers of fine-grained soils slow the vertical movement of groundwater between water-bearing layers.

Elliott/Western Connector

This area consists of two general soil and groundwater conditions: the conditions along the waterfront and the conditions in the upland area north and east of about First Avenue. Soil and groundwater conditions along the waterfront in the area of the proposed Elliott/Western Connector are similar to those described in the preceding Elliott Bay Seawall and Waterfront section.

In the upland areas, the regional water table is generally between 100 and 135 feet below the ground surface, depending on the ground surface elevation. However, perched groundwater likely exists in isolated zones in the upland area, between the ground surface and 100 feet below the ground surface. Apart from these perched zones, the fine-grained soils are generally unsaturated down to the water table aquifer in the fluvial soils. Groundwater fluctuations due to tidal fluctuations that were noted along the waterfront decrease inland between First Avenue and Fourth Avenue.

The relative hydraulic conductivity of the upland soils is low for the fine-grained deposits and high for the coarse-grained deposits. The horizontal hydraulic gradient is generally to the west toward Elliott Bay. The direction of flow for shallow, perched groundwater is locally controlled by the geometry and extent of the soils on which it is perched and the near-surface topography.

4.8 Groundwater Recharge and Discharge

Recharge to the aquifers in the study area occurs as precipitation (rain) infiltrates (penetrates) the ground surface within and east of the study area. The average annual precipitation for the Seattle area is approximately 34 inches. Recharge by precipitation is controlled by a number of parameters, including ground slope, the amount of paved area, and the soil’s ability to transmit water. In areas where the ground slope is steep, water will run off the face of the slope, and little water will infiltrate the subsurface on the slope. At the base of the slope, the runoff may collect and recharge depending on the amount of paved area and soil conditions. In paved areas, precipitation will run off the area, typically to the combined sewer system or to the storm drain system that discharges to Elliott Bay. Therefore, in areas with a high density of buildings and pavement, little recharge is likely to occur. The rate at which precipitation infiltrates is a function of soil conditions, particularly the soil's ability to transmit water. In areas where the near-surface soil consists of silt or clay, water does not readily infiltrate.

Hydraulic gradients measured in aquifers underlying the study area indicate that the direction of groundwater movement is west toward Elliott Bay and east toward Lake Union. The main area of discharge is Elliott Bay, except in the northern part of the study area, where shallow groundwater likely discharges to Lake Union.

4.9 Current Aquifer Use and Institutional Use Prohibitions

No active drinking water wells have been identified in the study area; however, a review of Ecology water rights records indicates that two active water rights for groundwater withdrawal exist near the study area. A groundwater certificate was issued for the former Troy Laundry Company located at the corner of Thomas Street and Fairview Avenue N. The certificate was issued in 1971 for groundwater withdrawal from a well. The current status of the well is unknown. A groundwater right has been issued for Safeco Field for irrigation of the playing field. The water supply is from the permanent drainage system beneath the sports facility.

Two additional water rights are known to exist within approximately 1 mile of the study area. A groundwater right has been issued for the Port of Seattle at Terminal 91. The Terminal 91 well, which is located in the upland area north of the Galer Street Viaduct, is screened from 340 to 445 feet below the ground surface and is used for industrial water supply. A groundwater right for an emergency backup water supply well has been issued for Swedish Medical Center/Providence campus, which is located at 500 17th Avenue.

Because of the presence of a municipal water system in the Seattle area, groundwater use is generally limited to emergency and industrial supply wells for non-drinking use. The nearest known drinking water wells are the Highline Aquifer system wells, located north of the Seattle-Tacoma International (Sea-Tac) Airport (about 6 miles south of the southern edge of the study area), which are part of the City of Seattle water system. These wells are screened in older coarse-grained deposits. This aquifer is not in hydraulic connection with the aquifers below the study area.

4.9.1 Sole Source Aquifers

No sole source aquifers are located within 5 miles of the study area.

4.9.2 Wellhead Protection Areas

The study area does not overlap with any wellhead protection areas. The nearest wellhead protection area is for the Highline Aquifer system wells. The study area is outside of the 10-year capture zone for the Highline Aquifer wellhead protection area.

Chapter 5 OPERATIONAL EFFECTS, MITIGATION, AND BENEFITS

Earth- and groundwater-related effects caused by the Bored Tunnel Alternative would be effects on existing structures, utilities, and buildings along the alignment. The features of the Bored Tunnel Alternative that may affect the earth and groundwater environment during operation include the bored tunnel, cut-and-cover tunnel, retained cuts, new buildings, and retaining walls. No earth- and groundwater-related operational effects are anticipated for at-grade roadway improvements, new signs or signals, or paving.

Operational effects are those that occur over the long term as the facility is in operation. The following sections discuss different types of operational effects, mitigation, and benefits for the Viaduct Closed (No Build Alternative) and the Bored Tunnel Alternative.

5.1 Operational Effects of the Viaduct Closed (No Build Alternative)

Both federal and Washington State environmental regulations require agencies to evaluate a No Build Alternative to provide baseline information about existing conditions in the project area. For this project, the No Build Alternative is not a viable alternative because the existing viaduct is vulnerable to earthquakes and structural failure due to ongoing deterioration. Multiple studies of the viaduct's current structural conditions, including its foundations in liquefiable soils, have determined that retrofitting or rebuilding the existing viaduct is not a reasonable alternative. At some point in the future, the roadway will need to be closed.

The Viaduct Closed (No Build Alternative) describes what would happen if the Bored Tunnel Alternative or another build alternative is not implemented. If the existing viaduct is not replaced, it will be closed, but it is unknown when that would happen. However, it is highly unlikely that the existing structure could still be in use in 2030.

The Viaduct Closed (No Build Alternative) describes the consequences of suddenly losing the function of SR 99 along the central waterfront based on the two scenarios described below. All vehicles that would have used SR 99 would either navigate the Seattle surface streets to their final destination or take S. Royal Brougham Way to I-5 and continue north. The consequences would be short-term and would last until transportation and other agencies could develop and implement a new, permanent solution. The planning and development of the new solution would have its own environmental review.

Two scenarios were evaluated as part of the Viaduct Closed (No Build Alternative):

- Scenario 1 – An unplanned closure of the viaduct for some structural deficiency, weakness, or damage due to a smaller earthquake event.
- Scenario 2 – Catastrophic failure and collapse of the viaduct.

As stated in Section 4.4.4, there is a high liquefaction hazard along the downtown Seattle waterfront and in the south portal area. For the Viaduct Closed (No Build Alternative), the existing viaduct would continue to be susceptible to damage caused by ground shaking and liquefaction of the foundation soils during an earthquake. Liquefaction could also result in lateral spreading along Elliott Bay and the Duwamish Waterway. During an earthquake, the existing viaduct structure, seawall, utilities, and adjacent buildings may settle, move laterally, tilt, or collapse due to liquefaction and lateral spreading. The degree to which this could occur would depend on the foundation soils, the properties of the structures, and the magnitude and duration of the ground shaking. Surface fault rupture from an earthquake on the Seattle Fault could also result in widespread damage to structures near and within the rupture area.

5.2 Operational Effects of the Bored Tunnel Alternative

The Bored Tunnel Alternative includes a 1.7-mile-long bored tunnel beneath downtown Seattle, south and north portal areas with associated surface street improvements, removal of the existing viaduct, and decommissioning of the Battery Street Tunnel. The south end of the Bored Tunnel Alternative is located near S. Royal Brougham Way, and the north end is located near Mercer Street.

The Bored Tunnel Alternative includes bored and cut-and-cover tunnels, retained cuts, and tunnel operations buildings. The Bored Tunnel Alternative is being designed based on available subsurface information, design procedures and criteria approved by WSDOT, and existing site conditions. The following sections describe the earth- and groundwater-related effects that could result from operation of the Bored Tunnel Alternative.

5.2.1 South Portal Area

At the south portal of the bored tunnel near the intersection of S. King Street and Alaskan Way, the double-level roadway would extend to the south and unbraid as it becomes shallower. About the first 1,000 feet of the roadway south of the bored tunnel portal would be within a cut-and-cover structure. At the south end of the cut-and-cover section, the roadway would be side-by-side and extend about 15 and 25 feet below the ground surface for the southbound and northbound alignments, respectively. The side-by-side roadway would extend about another 550 feet in a retained cut before reaching existing grade north of S. Royal Brougham Way. On- and off-ramps would also be constructed in retained cuts on either side of the side-by-side main roadway. The retained cuts and cut-and-cover sections of the roadway and ramps would likely be supported by diaphragm walls, such as secant pile walls or slurry walls. The south portal area would also include a tunnel operations building, located in the block bounded by S. Dearborn Street, Alaskan Way S., and Railroad Way S. Portions of the building would extend underground to match the tunnel grade in this area (up to about 75 feet below the ground surface).

In the south portal area, two options are being considered for new east-west cross streets that would be built to intersect with Alaskan Way S.:

- New Dearborn Intersection – Alaskan Way S. would have one new intersection and cross street at S. Dearborn Street. The cross street would have sidewalks on both sides.
- New Dearborn and Charles Intersections – Alaskan Way S. would have two new intersections and cross streets at S. Charles Street and S. Dearborn Street. The cross streets would have sidewalks on both sides.

The Bored Tunnel Alternative in the south portal area also includes constructing east-west surface streets along S. Charles Street and S. Dearborn Street and constructing a north-south City Side Trail east of the new SR 99 roadway. These streets would be constructed at grade. Several fills may be constructed to connect the SR 99 roadway to the new mainline elevated structure south of S. Royal Brougham Way and within the cut-and-cover sections above the finished roadway structures. There would be no substantial differences in effects between the two options being considered.

Groundwater

The water table in the south portal area is about 2 to 12 feet below the ground surface. Groundwater flow could be altered by the presence of the walls supporting the retained cuts and cut-and-cover tunnel and ground improvement areas. The retaining walls would extend about 1,500 feet south of the bored tunnel portal. The walls would essentially block the flow of groundwater and could cause a higher groundwater level to mound up against the wall. Groundwater mounding may occur along the east sides of the walls since groundwater flow is generally westward, toward Elliott Bay. A higher water table would not cause soil settlement; however, utilities and other subsurface structures that were previously above the water table east of the walls could be partially submerged and/or experience uplift forces due to buoyancy if groundwater mounding occurs. Areaways and basements adjacent to the alignment could also experience leakage or partial flooding if groundwater mounding occurs.

Erosion and Sediment Transport

Most of the roadway in the south portal area would be below grade. Therefore, surface water runoff would generally move toward lower areas and drain into the roadway drainage systems. This may result in buildup of sediment in the drainage systems. If the sediment buildup is sufficient and the drainage system is not maintained, this could result in water accumulation in the bottom of the retained cuts and cut-and-cover tunnel. For surface road features, sediment erosion and transport into surface water could occur if surface water runoff is not controlled. The eroded sediments could be deposited on adjacent properties, in streets, or in Elliott Bay.

Utilities

Existing utilities are present within the footprint of the proposed roadway and ramps; therefore, temporary or permanent relocation of the utilities may be required before retaining walls and foundations are constructed, as discussed further in Appendix K, Public Services and Utilities Discipline Report. Abandoned utilities that are not backfilled could become conduits for water, gases, or contamination, which could affect existing or future facilities. If the abandoned utilities are not backfilled, breaks in the pipes or joints could result in erosion of soil around the pipes, which could result in ground settlement.

Retained Cut and Cut-and-Cover Structures

The cut-and-cover structure and most of the retained cut structures in the south portal area would extend below the water table. This would result in uplift pressures (due to buoyancy) on the base of the structures. If the downward forces of the structure's weight and the uplift resistance of the structure's foundations do not adequately resist these uplift pressures, damage to the cut-and-cover or retained cut structures could occur.

Settlement and lateral movement could occur adjacent to retaining walls over the long term if the walls are not properly designed for the soil and groundwater conditions and applied surcharge loads. If walls are located adjacent to existing facilities, settlement and lateral movement of the adjacent structures could occur. In addition, lateral movement of the wall may cause cracks to form that would allow migration of soil and water through the wall. This would result in deposition of soil and water onto the roadway.

Fills

Several sections in the south portal area may include placement of fill to align roadways and restore surface grade. A small fill embankment (generally less than 6 feet high) may be constructed over S. Royal Brougham Way for the mainline roadway. The soil conditions beneath this fill consist of loose sand and soft silt. In addition, several large utilities are located beneath the proposed fill. Soft and loose soil deposits are susceptible to large magnitudes of settlement. In areas where primarily sandy soils are present, settlements would occur as the load is applied. However, where soft clayey soils are present, settlements could occur more slowly, over a period of several months to more than a year, depending on the clay and organic content of the soil and the thickness of the soft clayey soil unit. The presence of soft soils beneath the fill could also result in lateral movement as the subsurface soil compresses under the weight of the fill. Lateral movement near the toe of a fill embankment could be as much as one-half of the estimated settlement. Existing adjacent utilities or structures could be subjected to lateral loading due to this movement.

Existing utilities that are located below the fill areas would be subjected to loading and settlement due to the overlying fill. The settlement may also extend out from the toe of the new fill embankment, resulting in potential settlement of adjacent facilities such as existing roadways, railways, buildings, and utilities. Settlement of fill embankments adjacent to buried foundations or walls could result in loading of those foundations and walls by a process called downdrag. As the soil settles, friction along the side of the adjacent foundation would add additional downward force as the foundation or wall is dragged down by the soil. For foundations and walls that are not designed for this additional load, damage to the structures that are supported by these foundations or walls could occur. This would be a concern for both the permanent walls of the retained cut and cut-and-cover sections and existing foundations of surrounding structures.

Other fill areas would be located within the retained cuts and cut-and-cover sections to achieve the required grades for the roadway surfaces and to cover the tunnel structure and restore the ground surface grade. Use of unsuitable fill materials (such as those containing debris and organics), fill placement in wet conditions, or improper fill placement and compaction methods could result in excessive settlement of the fill over time, regardless of the subsurface conditions. This would result in damage to any facilities that are supported by the fill (e.g., utilities).

Foundations

The proposed tunnel operations building would likely be supported on deep foundations consisting of drilled shafts or a mat foundation.

Mat foundations would be installed at the base of the tunnel operations building excavation by placing a reinforced-concrete slab on the excavated subgrade. If soft areas are present in the subgrade, settlement of the mat foundation could occur over time. Tiedowns may be used to resist uplift forces caused by buoyancy. These tiedowns would be drilled down into the underlying soils to achieve soil resistance. Improper installation of the tiedowns could result in insufficient soil resistance, which could result in movement or cracking of the mat foundation and resulting water leakage into the building basement.

Ground Improvement

Specific areas of ground improvement have not been selected for the south portal area. During final design, ground improvement may be required around or beneath retained cuts, cut-and-cover tunnel sections, or foundations to mitigate liquefaction, reduce groundwater flow, and provide additional soil strength. In areas where ground improvement is used to mitigate liquefaction, the soil outside the ground improvement area would still liquefy. This could result in differential settlement between the ground improvement zone and the surrounding area. Differential settlement could result in damage to utilities and structures.

If ground improvements are not installed correctly, the stability and integrity of the structures in the ground improvement area could be affected. For example, when performing deep soil mixing, portions of the soil may not be adequately improved if the deep soil mixed columns are not designed or constructed properly. This could result in partial liquefaction in some areas, increased water inflow, and higher loads on the retaining walls or foundations.

5.2.2 Bored Tunnel

The bored tunnel alignment would start at the south end near S. King Street and extend north generally along Alaskan Way, west of the existing viaduct. North of S. Washington Street, the tunnel would extend under the existing viaduct near Yesler Way. At this location, the top of the tunnel would be about 20 feet below the tips of the piles supporting the existing viaduct. North of Yesler Way, the tunnel would extend beneath buildings until about University Street, where the tunnel would be located beneath First Avenue. The tunnel would continue along First Avenue and then turn north near Stewart Street until it ends near the intersection of Sixth Avenue and Thomas Street. The bored tunnel would be approximately 1.7 miles long and 54 feet in diameter. At the south portal of the bored tunnel, the tunnel crown would be about 30 feet below the ground surface. The maximum depth of the tunnel crown (about 215 feet below the ground surface) would be located near Virginia Street. At the north portal of the bored tunnel, the tunnel crown would be about 30 feet below the ground surface. The roadway in the bored tunnel would be a double-level configuration, with the southbound lanes on the upper level and the northbound lanes on the lower level.

The bored tunnel alignment would cross beneath numerous buildings between Yesler Way and University Street and north of Stewart Street. Ground improvement may be installed beneath some of these buildings to mitigate potential settlement caused by tunneling. In addition, ground improvement may be performed along Alaskan Way between S. King Street and S. Jackson Street to improve the recent soil deposits along the crown of the tunnel. Ground improvement may also be performed near Yesler Way where the bored tunnel would extend beneath the existing viaduct. Numerous utilities in these areas would require relocation or support during the ground improvement/ replacement process.

At two locations along its alignment, the bored tunnel would pass beneath existing subsurface tunnels. Near Pike Street, the bored tunnel would pass under the existing BNSF railroad tunnel. The railroad tunnel invert is located about 90 feet below the ground surface and about 90 feet above the proposed crown of the bored tunnel. The Elliott Bay Interceptor (EBI), which is a 12-foot-diameter, brick-lined sewer, is located about 160 feet below the ground surface between about Virginia Street and Lenora Street. The crown of the proposed bored tunnel would be located about 45 feet below the EBI. A lateral adit structure pipe connects to the EBI and also crosses over the proposed location of the bored tunnel at Pike Street (Pike Street Adit structure). At this location, the crown of the bored tunnel would be about 70 feet below the Pike Street Adit structure.

The soil conditions along the bored tunnel alignment generally consist of very dense, hard soils that have been compacted by the weight of glaciers (see Section 4.3.2). Because the net weight of the tunnel would likely be less than that of the soil that is removed, the tunnel structure would not place additional loads on the soil. Most of the earth- and groundwater-related effects of the bored tunnel would be associated with construction as the tunnel is excavated (see Section 6.1.2).

Erosion and Sediment Transport

The roadway in the bored tunnel would be below grade. Runoff would generally move toward lower areas and drain into the tunnel drainage systems. This may result in buildup of sediment in the drainage systems. If the sediment buildup is sufficient and the drainage system is not maintained, this could result in water accumulation in the bottom of the tunnel.

Groundwater

The water table between S. King Street and Yesler Way is within about 10 feet of the ground surface. In some areas, artesian water conditions are present, as discussed in Section 4.7.2. Groundwater flow may be altered by the presence of the bored tunnel and potential ground improvement between S. King Street and S. Jackson Street. The ground improvement, which may include cement-treated ground, and the bored tunnel could obstruct the groundwater flow and could cause a higher groundwater level to mound up against the east side of the tunnel alignment. A higher water table would not cause soil settlement; however, utilities and other subsurface structures that were previously above the water table could become partially submerged if groundwater mounding occurs.

Areaways and basements adjacent to the alignment could also experience leakage or partial flooding if groundwater mounding occurs.

Groundwater mounding along the bored tunnel north of Yesler Way is not anticipated. The lower aquifers that intersect the 54-foot-high tunnel horizon are widespread, interconnected, and highly pervious, allowing water to flow around the tunnel.

Tunnel Structure

The bored tunnel would be located partially or completely below the water table along the entire alignment. Uplift pressures (due to buoyancy) would act on the base of the tunnel structure. In most areas, the tunnel structure would have sufficient cover (soil above the tunnel crown) to resist these uplift pressures. However, south of S. Jackson Street, the tunnel may not have enough soil cover to resist the uplift pressures. If the downward forces of the tunnel structure's weight plus the overlying soil cover and the uplift resistance of the tunnel structure do not adequately resist these uplift pressures, deflection of the roadway could occur. Large deformations could cause structural cracking of the concrete liner segments. In addition, openings could develop in the tunnel liner and create pathways for groundwater leakage. Openings would initially occur at the construction joints between gasketed liner segments.

If the tunnel liner opens, ground settlement could eventually occur. Groundwater could seep through the openings and cause erosion of the soil around the tunnel. Left unchecked, this could eventually result in the formation of a cavity around the tunnel, which could migrate to the ground surface and cause settlement of surface features. The loss of soil could eventually result in loss of passive resistance at the liner segment, resulting in a deteriorating cycle of increased liner deformation and structural damage, further opening of joints or cracking of segments, and increased groundwater seepage and ground loss.

5.2.3 North Portal Area

At the north portal of the bored tunnel near the intersection of Sixth Avenue and Thomas Street, the double-level roadway would exit the tunnel and extend north into a cut-and-cover structure for the first 450 feet as it unbraids and becomes shallower. At the north end of the cut-and-cover section, the northbound and southbound roadways would be side-by-side and about 35 and 20 feet below the ground surface, respectively. The roadways would continue in a retained cut and reach existing grade about 400 feet farther to the north, near Broad Street, which would be filled in as part of the Bored Tunnel Alternative. On- and off-ramps would be constructed for northbound and southbound traffic. The retained cuts and cut-and-cover sections of the roadway and ramps would likely be supported by soldier pile and lagging walls and/or diaphragm walls, such as secant pile walls. The north portal area would also include a tunnel operations building located east of Sixth Avenue N., between Thomas Street and Harrison Street. Portions of the building would extend underground to match the tunnel grade in this area (up to about 80 feet below the ground surface).

The Bored Tunnel Alternative also includes constructing several surface streets over the cut-and-cover portion of the SR 99 roadway to reconnect the surface street grid at John Street, Thomas Street, and Harrison Street. The retained cut roadway along Mercer Street from Fifth Avenue N. to Dexter Avenue N. would be widened from four lanes to six lanes, requiring construction of new retaining walls for the widened roadway.

A connection from Mercer Street to the surface street grid would be constructed along Sixth Avenue N. Two configuration options are being considered for this connection. The Curved Sixth Avenue option would move Sixth Avenue N. east along a curved alignment so that it would intersect Mercer Street closer to SR 99. The Straight Sixth Avenue option would extend Sixth Avenue N. in a straight alignment until it intersects Mercer Street. For either option, the Sixth Avenue connection would require a retained cut, about 20 feet deep at Mercer Street, extending south until it reaches existing grade near Broad Street. The Broad Street retained cut roadway would be closed and filled in from Taylor Avenue N. to about Ninth Avenue N. Other fills would also be placed within the cut-and-cover sections above the finished roadway structures to restore the surface grade.

Erosion and Sediment Transport

Most of the roadway in the north portal area would be below grade. Therefore, surface water runoff would generally move toward lower areas and drain into the roadway drainage systems. This may result in buildup of sediment in the drainage systems. If the sediment buildup is sufficient and the drainage system is not maintained, this could result in water accumulation in the bottom of the retained cuts and cut-and-cover tunnel. For surface roadway features, sediment erosion into surface water could occur if surface water runoff is not controlled. The eroded sediments could be deposited on adjacent properties, in streets, or in Lake Union.

Utilities

Temporary or permanent relocation of existing utilities may be required before retaining walls and foundations are constructed. Abandoned utilities that are not backfilled could become conduits for water, gases, or contamination, which could affect existing or future facilities. If the abandoned utilities are not backfilled, breaks in the pipes or joints could result in erosion of soil around the pipes, which could result in ground settlement.

Retained Cut and Cut-and-Cover Structures

Settlement and lateral movement could occur adjacent to retaining walls over the long term if the walls are not properly designed for the soil and groundwater conditions and applied surcharge loads. If walls are located adjacent to existing facilities, settlement and lateral movement of the adjacent structures could occur. In addition, lateral movement of the wall may cause the formation of cracks that would allow migration of soil and water through the wall. This would result in deposition of soil and water onto the roadway.

Fills

The Bored Tunnel Alternative includes filling in the existing retained cut along Broad Street. Fills would also be placed over the tunnel structure in the cut-and-cover sections and in several other areas to provide connections between the new roadways and the surrounding street grid and to restore the surface grade. In general, the soil conditions beneath the proposed fills would be hard or dense. Use of unsuitable fill materials (such as those containing debris and organics), fill placement in wet conditions, or improper fill placement and compaction methods could result in excessive settlement of the fill over time, regardless of the subsurface conditions. This would result in damage to any facilities that are supported by the fill (e.g., utilities).

Foundations

The proposed tunnel operations building would be supported on shallow or deep foundations. Lateral loading on the foundations may result in lateral loading of the subsurface portions of adjacent facilities (e.g., basement walls and utilities). This could result in deflection or damage to the adjacent facilities.

The bearing capacity of shallow spread footing foundations depends on the subgrade soils. If footing subgrades are not properly prepared or if they contain soft or wet zones, excessive settlement of the footing could occur once loading is applied. New spread footings located adjacent to existing walls, utilities, or other structures could result in loading and damage to the adjacent facilities. Typically, the vertical load on a footing would distribute itself such that, at a given depth, load from the footing extends out a distance from the edges of the footing equal to 50 to 100 percent of that depth. If adjacent facilities are within this load distribution zone, damage to the adjacent facilities could occur.

5.2.4 Viaduct Removal

The Bored Tunnel Alternative includes relocating the utilities on the existing viaduct and demolishing the viaduct. About 2 feet of excavation would be performed to remove existing viaduct foundation caps. Demolition of the viaduct would have no earth- or groundwater-related operational effects. A benefit of the viaduct removal would be elimination of the possibility that soil liquefaction and potential seawall failure would cause a collapse of the viaduct.

5.2.5 Battery Street Tunnel Decommissioning

The Battery Street Tunnel would be decommissioned as part of the Bored Tunnel Alternative. The current proposal is to partially fill the tunnel with crushed rubble recycled from the viaduct removal. The remainder of the empty space in the tunnel would then be filled with concrete slurry to provide a continuous backfill. No earth- or groundwater-related effects are anticipated for the decommissioning of the Battery Street Tunnel.

5.3 Operational Mitigation

Mitigation measures for the operational effects identified in Section 5.2 are based on site and subsurface information and standard design and construction procedures in use at the time of this report's preparation. Most of the earth- and groundwater-related effects can be mitigated through proper design, construction, and maintenance of the features included in the Bored Tunnel Alternative.

5.3.1 Mitigation Common to All Areas

Many of the operational effects identified in Section 5.2 are common to all areas of the Bored Tunnel Alternative. This section discusses mitigation measures for these effects are discussed in this section.

Exploration and Design Approach

The Bored Tunnel Alternative is being designed by experienced engineers based on the existing site conditions, available subsurface information, and design procedures and criteria approved by WSDOT and the City of Seattle. To adequately define the subsurface conditions, subsurface data have been obtained at 100- to 300-foot intervals along the bored tunnel alignment and at 100- to 200-foot intervals along the portal areas (a total of about 80 subsurface explorations). The explorations extend to depths of about 30 to 50 feet below the tunnel invert. This exploration program partially mitigates the potential for unknown subsurface conditions to affect the earth and groundwater during the operation of the Bored Tunnel Alternative.

Erosion and Sediment Transport

Design of drainage features for the Bored Tunnel Alternative will require consideration of the anticipated surface runoff from the site features over the long term. Drainage facilities in the tunnel should be sized to contain the anticipated volume of runoff and other drainage water over the long term. Periodic maintenance and cleaning of the drainage features should also be performed to mitigate sediment collection. Proper design, construction, and maintenance of the drainage facilities would mitigate potential deposition of water in the tunnel and erosion and sediment transport onto adjacent properties, roadways, tracks, or water bodies.

Utilities

Numerous existing above-grade and underground utilities would be affected by the Bored Tunnel Alternative, especially in the south and north portal areas. For utilities that are located within retained cut areas, relocation of the utilities would likely be required, as discussed in Appendix K, Public Services and Utilities Discipline Report. In some areas, it may be possible to make minor adjustments to foundation or wall types and locations to avoid effects on existing utilities. For example, secant pile walls can be adjusted to span or provide gaps for utilities. In areas where a cut-and-cover tunnel would be constructed, some utilities could be supported in place during construction so that relocation would not be necessary. Abandoned utilities should be backfilled with cement grout or other suitable backfill materials so that they cannot become conduits for water or gases.

5.3.2 South and North Portal Areas

Both the south and north portal areas would contain surface roadways, cut-and-cover tunnels, retained cut structures, and tunnel operations buildings. This section discusses mitigation measures for the operational effects associated with these types of structures. Ground improvement may be performed to improve soil conditions and mitigate potential effects, especially in the south portal area. This section also presents mitigation measures for earth- and groundwater-related operational effects associated with ground improvement.

Groundwater

Groundwater monitoring devices have been installed in the study area to evaluate the groundwater levels over time. These devices measure groundwater levels approximately monthly. Groundwater mounding will be evaluated for all walls or ground improvement zones that are longer than about 100 feet and may block groundwater flow. If the magnitude of the groundwater mounding is less than the current measured natural fluctuation of groundwater in the soil, then no mitigation measures would be necessary. If higher mounding is anticipated, then mitigation measures could consist of providing a path for groundwater through the retaining walls or ground improvement zones. This could be achieved by constructing pipes or drainage trenches that connect the groundwater flow between the west and east sides of the wall or zone. Alternatively, if feasible for the design, gaps could be left in the ground improvement zones to allow groundwater to flow through the unimproved areas. Groundwater mounding along the bored tunnel is not anticipated, as discussed in Section 5.2.2.

Retained Cut and Cut-and-Cover Structures

Mitigation for the effects related to retaining walls includes properly designing the walls, defining the location and extent of unstable soils, and using proper construction procedures. Tiebacks, soil nails, or other bracing may be used to improve the stability of retaining walls by providing additional lateral resistance to the earth pressures behind the wall. Minimizing unsupported wall heights and/or using stiffer wall systems would mitigate potential ground movement. The base of the walls should extend a sufficient depth into undisturbed soils so that adequate passive resistance in front of the wall is generated to resist the lateral earth pressures behind the wall and provide global stability.

To mitigate potential uplift due to groundwater pressures on the retained cut and cut-and-cover tunnel structures, the walls could be extended deeper into the subsurface soils to achieve additional uplift resistance. Also, tiedowns connected to the structure base slab could provide additional uplift resistance.

To mitigate potential seepage of water into the permanent retained cut and cut-and-cover structures, waterproofing would likely be installed around the perimeter of the permanent structure. This waterproofing may consist of either self-adhering membranes or prefabricated sheeting placed below the bottom and along the sides of the structures inside the temporary excavation support system.

Fills

Fills would be placed over the roadway structures in the retained cuts and cut-and-cover sections of the south and north portal areas and in the existing depressed roadway along Broad Street. Suitable structural fill materials should be used to construct the fills. In general, structural fill materials should consist of sand and gravel with a low content (less than 30 percent) of fines (silt and clay). The material should be compacted to the compaction criteria required by WSDOT. In wet weather conditions, cleaner (less than 5 percent fines) structural fill materials may be required.

In areas where fills would be constructed over soft soil conditions, such as those present in the south portal area, the fills would be designed with consideration of anticipated settlement and lateral movement and the associated effects on adjacent structures. Existing deep foundations, permanent walls, or other buried structures would be evaluated for potential downdrag loads caused by settlement of adjacent fills. New deep foundations and permanent walls would be designed to accommodate the additional compressive loads caused by downdrag. Alternatively, for deep foundations, construction sequencing could be performed so that the foundations are installed after most of the settlement due to the fills has occurred. Another potential mitigation measure for foundations would consist of using casing in the upper soils to reduce the negative skin friction (downdrag) on the foundation. If the estimated downdrag loads or settlement cannot be accommodated, lightweight fill could be used to reduce the settlement and corresponding downdrag. Alternatively, ground improvement could be performed. If the settlement and downdrag loads cannot be accommodated by these other methods, foundation elements such as piles could be installed to support the fill embankments.

Mitigation for slope stability of fills under earthquake loading could be achieved by performing ground improvement beneath and adjacent to the fill areas. Geotextiles (reinforcing elements) could also be used within the fill material to provide additional strength and resistance to failures.

Foundations

The effect of lateral loading on adjacent basement walls, utilities, footings, or piles would be mitigated by using proper design procedures to ensure that the lateral pressures do not exceed the capacity of the adjacent structures. Other mitigation measures that could be considered include improving the adjacent structures to accommodate the additional loads, moving foundation elements farther from existing structures, and performing ground improvement to distribute the loading.

Mat foundations may be used for the tunnel operations buildings. The thickness of the mat can be increased to resist buoyancy forces caused by groundwater. Alternatively, tiedowns may be used. Proper preparation of the subgrade below the mat foundation and installation of tiedowns would mitigate potential movement and cracking of the mat foundation.

Shallow footings that may be used for structures in the north portal area would be properly designed to mitigate additional loading on adjacent facilities. If loading on adjacent facilities is a concern, the footing could be deepened, a deep foundation could be used, or the footing could be moved farther away from the adjacent facility.

Ground Improvement

Proper construction techniques and monitoring of the construction quality should be performed to confirm that the desired degree of ground improvement is being achieved. For example, with stone columns, density tests using the cone penetrometer can be performed before and after the improvement to confirm the degree of ground improvement achieved. For deep soil mixing and jet grouting, core samples can be obtained at various depths and tested for strength. Additional ground improvement could then be installed in areas where ground improvement is insufficient.

5.3.3 Bored Tunnel

Most of the earth- and groundwater-related effects for the bored tunnel are related to construction rather than operation. This section includes mitigation measures for the operational effects identified for the bored tunnel structure. Section 5.3.1 discusses other mitigation measures for effects that are common to all areas.

Groundwater

Groundwater mounding is a potential effect of the ground improvement that may be performed beneath buildings and along Alaskan Way south of Yesler Way. Mitigation measures for this condition would be similar to those presented in Section 5.3.2.

Tunnel Structure

To mitigate potential uplift of the tunnel structure near the south portal, additional weight could be added to the tunnel structure as ballast. Long-term monitoring and maintenance of the tunnel liner should be performed to evaluate whether openings are developing between the liner segments and whether groundwater seepage and soil migration are occurring through the openings. If an opening is noted, grouting of the opening could be performed to mitigate potential groundwater seepage and migration of soil from behind the tunnel liner. If cavities form behind the wall, additional grout may need to be injected behind the liner to fill the cavities and prevent loosening of the soil around the tunnel.

5.4 Operational Benefits

During a seismic event, the soil along the existing viaduct would likely liquefy, causing a large reduction in soil strength. Also, the existing Alaskan Way Seawall would likely fail. If the viaduct is removed and traffic is moved to the bored tunnel, then the soil liquefaction and potential seawall failure would not affect SR 99 traffic.

The Battery Street Tunnel may also sustain damage during a seismic event. Since the Bored Tunnel Alternative includes decommissioning of the Battery Street Tunnel, the potential for high-cost financial effects or loss of life would be greatly reduced.

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Chapter 6 CONSTRUCTION EFFECTS AND MITIGATION

6.1 Construction Effects

The potential earth- and groundwater-related effects of the Bored Tunnel Alternative would generally be related to the effects of earthwork on existing features (e.g., structures and utilities). The Bored Tunnel Alternative features that may affect the earth and groundwater environment during construction include the bored tunnel, excavations, new building foundations, and retaining walls.

Construction effects are primarily related to earthwork and occur during construction or within a short time thereafter. The Viaduct Closed (No Build Alternative) does not include earthwork; therefore, no construction effects would occur. The following sections present discussions of different types of construction effects and related mitigation measures for the Bored Tunnel Alternative.

The Bored Tunnel Alternative would be constructed using appropriate BMPs (WSDOT and City of Seattle). If subsurface conditions encountered during construction in the project area are different from those assumed in the design, future unanticipated effects on the project area could occur.

6.1.1 South Portal Area

Section 5.2.1 includes a description of the south portal area. Earthwork for the south portal area primarily includes construction of large retained excavations for the retained cut and cut-and-cover tunnel sections. Along the cut-and-cover section, the retained excavation would be filled in after the roadway structure is constructed. At the south portal of the bored tunnel, the adjacent retained excavation would be about 70 feet wide and 95 feet deep to accommodate launching of the TBM. Extending toward the south, the excavation would become shallower and wider as the roadway extends toward grade and unbraids, and as on- and off-ramps are added. When the roadway reaches grade about 600 feet north of S. Royal Brougham Way, the total width of the southbound and northbound roadway lanes and the on- and off-ramps would be about 200 feet. The retained cuts required to construct the on- and off-ramps may be constructed in separate excavations or may be included with the southbound and northbound roadway in one large retained cut. Following construction of the SR 99 roadway and ramps, the cut-and-cover portion of the excavations would be filled in to restore the grade. Surface streets would then be constructed over the cut-and-cover tunnel area to reconnect the street grid.

The tunnel operations building (located east of Alaskan Way and north of S. Dearborn Street) would have underground levels extending as deep as 80 feet below the ground surface. Other earthwork in the south portal area includes construction of foundations for structures, grading for roadways, trenching for utilities, ground improvement, placement and compaction of fill, and removal of existing subsurface structures. In shallow excavation areas, such as utility trenches, temporary shoring may be used to provide excavation support. Construction dewatering would likely be required to control groundwater flow into the excavations that extend more than about 10 feet below the ground surface. Ground improvement may be performed in some areas to stabilize existing soft and loose soils, reduce groundwater flow, and mitigate potential future liquefaction. The earthwork would also generate the need for stockpiles and spoils handling and disposal.

Erosion and Sediment Transport

All surficial areas beneath fills, pavements, foundations, and other structures would be cleared of all existing pavement, vegetation, and debris and stripped of organic soils. The debris resulting from these clearing activities would be removed from the area. The prepared ground surface would have high erosion potential if exposed during the rainy season or in the presence of surface water. Any areas that are disturbed during construction would be subject to increased erosion if proper control measures are not performed.

Poor construction drainage practices may also contribute to the surface water flow and erosion. The surface soil could erode and drain into stormwater drains, into Elliott Bay, or onto adjacent properties or streets. The surface water flow could also result in drainage of water into excavations, which could cause instability of the excavations. The amount of erosion and sedimentation would depend on the amount of soil exposed or disturbed, weather and groundwater conditions, and the erosion control measures implemented. These effects and others related to surface water are presented in Appendix O, Surface Water Discipline Report.

Within construction areas, the tires and tracks of heavy equipment may sink into the soft surface soil if no work pad is present. The tires of the construction vehicles could also carry soil onto roadways when leaving construction areas and traveling along haul routes unless appropriate BMPs are implemented.

Existing Surface Features

Construction traffic may cause settlement, potholes, cracks, and other damage to existing roadways. The degree of damage to existing pavements would depend on the condition of the pavement subgrade, the pavement section strength, and the weight of construction traffic. Construction traffic may also cause settlement, displacement, and other damage to existing railroad tracks at current at-grade crossings.

Numerous utilities would be relocated to allow for construction of the Bored Tunnel Alternative. Installation of relocated utilities would require trenching and dewatering. Improper trenching and dewatering techniques could lead to settlement and lateral movement of adjacent facilities.

Temporary and Permanent Retaining Walls

Various retaining wall types may be selected to retain soils for the cut-and-cover tunnels, retained cut sections, tunnel operations building excavation, and other temporary and permanent excavations. Retaining wall types that may be used in the south portal area for shallower excavations include soldier pile and lagging walls, sheet pile walls, cantilever cast-in-place (CIP) concrete walls, and diaphragm walls (e.g., secant pile walls). For excavations deeper than about 15 feet below the ground surface, likely only diaphragm walls would be used. For all of these wall types, excessive settlement and ground movement adjacent to the wall could occur if the wall is not constructed properly. For example, ground movement could occur if loose soils or wet conditions are encountered during drilling for tiebacks or if tiebacks or braces are not properly installed at appropriate elevations. Excessive settlement and lateral deformation could affect or apply loads to nearby roadways, railways, utilities, and structures. Drilling to install tiebacks could damage utilities and structures located near the tieback.

Diaphragm walls would likely be used to support the sides of the cut-and-cover tunnel and deeper portions of the retained cuts. The advantage of diaphragm walls is that they can be used as temporary excavation support as well as act as the permanent retaining wall for the final structure. They are also relatively stiff compared to other walls, which would result in less ground deformation. Diaphragm wall types include deep soil mixing walls, slurry walls, secant pile walls, and tangent pile walls. In addition to supporting excavation sidewalls, diaphragm walls are relatively impermeable (prevent the passage of water), thus reducing groundwater flow into excavations. Diaphragm walls are generally more effective at preventing groundwater inflow than other wall types (e.g., soldier pile walls). After construction, areas between or adjacent to diaphragm walls would be excavated, and the diaphragm wall would serve as the retaining wall for the excavation. The diaphragm wall could be cantilevered, tied back, or internally braced. Improper design or construction of the diaphragm wall and tiebacks or braces could result in excessive lateral displacement, settlement, and subsequent loading of adjacent ground and nearby roadways, railways, utilities, and structures.

As discussed in Section 4.3.1, large amounts of wood and debris are located at some locations in the south portal area. Construction of retaining walls through this material may be difficult. If deep soil mixing walls are used, the augers would not be able to easily penetrate through the wood. If penetration is achieved, then the soil may not be fully mixed because of interference with the wood, which would result in a wall that could have discontinuities that could leak or be unstable. The presence of wood could also cause leakage and discontinuities in secant or tangent pile walls, although to a lesser extent.

Temporary shoring could be required for foundation excavations, utility trenching, or other shallow excavations. Improper or inadequate shoring construction or excessive deformation of shoring could contribute to settlement or lateral ground movement that could affect nearby facilities, utilities, and structures. In general, soil near shoring walls could have a settlement magnitude equal to about 50 to 100 percent of the wall's horizontal displacement. Vibration may also occur due to installation of some shoring types, such as sheet piles. Construction equipment working adjacent to the top of shoring walls may cause wall movement and ground settlement if the walls are not designed to accommodate the construction loads.

Excavations and Dewatering

Excavations would be made for relocation of utilities, construction of foundations, and excavation for retained cuts and cut-and-cover tunnels. Conventional equipment, including excavators and backhoes, would likely be used to perform the excavation. Excavations could cause sloughing of soils and lateral movement or settlement of nearby existing roadways, railways, structures, and utilities if proper excavation support and dewatering techniques are not used.

The water table in the south portal area is located about 2 to 12 feet below the ground surface. In areas where excavations extend below the water table, dewatering of soils within and below the excavation may be performed to control inflow, remove water from the excavation, and reduce hydraulic forces that could destabilize the excavation. Dewatering would be required for the construction of the cut-and-cover tunnels, most of the retained cut sections, and for the tunnel operations building excavation. Based on preliminary dewatering analyses, pumping rates along the alignment would vary widely depending on subsurface conditions and pumping duration; the rates may range from 100 to 1,000 gallons per minute per 100 feet of open excavation. Dewatering would occur until construction of the structure is completed. Handling and disposal of water generated during dewatering is addressed in Appendix O, Surface Water Discipline Report.

If the excavation dewatering effort were to fail or prove inadequate for any reason, ground loss may occur within the excavation. This loss could result from running (flowing) ground, piping, or base heave due to uplift conditions. This could cause settlement of utilities, roadways, and other facilities adjacent to the excavations.

Because of the presence of compressible soils near the excavations, dewatering could drawdown the water table outside the excavation. Drawdown outside of excavation would vary depending on the subsurface soil and groundwater conditions, the wall type, and the amount of dewatering required. Assuming a relatively impermeable wall (e.g., diaphragm wall) is used, preliminary groundwater drawdown estimates range from approximately 10 to 40 feet at a distance of about 400 feet from the wall. If the amount of drawdown is greater than the existing seasonal or tidal fluctuation of the groundwater, settlement of the ground surface could occur and potentially affect nearby roadways, railways, structures, and utilities. Settlement could also induce additional loads on nearby existing features. Where existing structures are founded on timber piles, extended groundwater lowering could contribute to pile decay.

Construction dewatering would not affect public or private groundwater supplies. Groundwater is not used as water supply in the study area. No wellhead, aquifer protection, or sole source aquifer plans exist in the area.

Stockpiles and Spoils Disposal

Spoils consist of soil or other debris that is removed from a construction activity. Based on the Bored Tunnel Alternative plans, between 400,000 and 450,000 cubic yards of material would be generated from the proposed excavations in the south portal area, depending on the option selected. All of this material would likely require off-site disposal. Transport and disposal of spoils are further discussed in Appendix B, Alternatives Description and Construction Methods Discipline Report.

Some of the spoils could be contaminated because they originate from the near-surface materials. The near-surface soils in the south portal area consist of manmade fill that contains debris and potential contaminants. Therefore, these soils cannot be reused as fill, but must be treated and disposed of according to State regulations. Disposal and volume estimates of these types of soils are further discussed in Appendix Q, Hazardous Materials Discipline Report.

Imported structural fill may be stored in stockpiles at staging areas located along the study area, as further discussed in Appendix B, Alternatives Description and Construction Methods Discipline Report. Effects of stockpiles may include settlement of the ground surface in the stockpile areas and erosion and sediment transport. Utilities and pavement beneath stockpiles could be damaged due to settlement and lateral movement caused by the weight of the stockpile materials. If the stockpiles are not suitably protected, surface water erosion could result in deposition of sediment onto adjacent properties, streets, and stormwater drains, or into Elliott Bay. Stockpiles of material to be used as landscaping or structural fill could become wet and unsuitable for use as fill if left uncovered during rainy periods.

Spoils that are removed from the site would be hauled in trucks, rail cars, or barges to a predetermined disposal site. During transport, spoils could spill, which could result in deposition of dust or debris on the roadways, on rail corridors, or in water unless appropriate BMPs are implemented.

Foundations

Foundations for the tunnel operations building in the south portal area would consist of deep foundations, such as drilled shafts or a mat foundation. Tiedowns may be used in areas where resistance to uplift is required.

Drilled shafts consist of reinforced-concrete piles that are constructed in drilled holes in the ground. Spoils are generated by removal of the soil from the drilled hole. After the hole is excavated, a reinforcement cage is lowered into the hole and the hole is backfilled with concrete. Because unstable soil and unfavorable groundwater conditions are present below the ground surface in numerous locations along the alignment, caving or sloughing of soil within open-hole excavations could affect nearby structures and utilities. Where unstable soil or unfavorable groundwater conditions are present, drilling mud would typically be used to stabilize the soil. In addition, in areas where adjacent structures require protection, a casing (with or without stabilizing drilling fluid) could be pushed, vibrated, or driven into the hole to support the shaft sides. Alternatively, oscillator or rotator shaft installation methods could be used to twist the casing into the ground. Noise and vibrations associated with casing installation could affect nearby people, structures, and utilities. Inadequate sidewall support or heave of the bottom of the hole could also cause settlement of nearby structures and utilities.

Ground Improvement

Ground improvement may be performed beneath or around foundations and the retained cuts and cut-and-cover tunnels to stabilize soft soils, reduce groundwater inflow, and mitigate potential liquefaction. Ground improvement could consist of deep soil mixing, jet grouting, or vibro-replacement (stone columns).

Jet grouting is typically performed by pushing, drilling, or jetting a grout pipe into the ground to the depth to be treated, and then forcing water and/or air through the pipe to erode the soil. Simultaneous with the water/air erosion of soil, cement grout is injected to mix with and replace the eroded soil. The resulting material is an engineered grout that solidifies in situ to become soil cement. Jet grout columns would be of variable diameters, with more erodible sands and silts forming a larger-diameter column (up to about 5 feet in diameter) than less erodible clays and glacial till soils.

If the jet grouting process is not properly controlled, gaps in the improved area could occur when soils that do not easily erode (e.g., clay) are encountered. In addition, when obstructions such as boulders, logs, piles, concrete, or other large debris are encountered, shadowing can occur (i.e., the obstruction would partially block the extent of the jet grouting), which would result in gaps in the improved zone. Gaps could also be created by misalignment of grout columns. Depending on the existing soil conditions, methods of construction, and extent of treated/untreated ground, utilities and foundation elements may settle or heave when jet grout operations are performed nearby. If jet grouting is performed near existing structures or utilities, excessive pressure could cause damage to the existing facilities. Depending on the jet grouting pressure and soil conditions, jet grout could also result in soil fracturing and leakage of grout into adjacent basements or areaways.

Jet grout operations typically produce spoil volumes equal to about 50 to 70 percent of the volume of soil treated. This spoil would consist of a mixture of eroded soil and cement grout that is flushed to the ground surface during jet grout operations. If not properly contained, spoil material may migrate onto adjacent streets or properties. Jet grout operations would not produce large vibrations.

Deep soil mixing is an in situ soil mixing technology that mixes existing soil with cement grout using mixing shafts consisting of auger cutting heads, discontinuous auger flights, and mixing paddles. The mixing equipment varies from single- to eight-shaft configurations, depending on the purpose of the deep soil mixing. If the augers are advanced or withdrawn too rapidly, or if grout pumping rates are not controlled, heave or settlement of nearby ground surface, utilities, and structures could occur. Depending on the equipment and operators, deep soil mixing could produce spoil equal to about 30 to 50 percent of the volume of soil treated. This spoil would consist of blended soil and cement. If not properly contained, spoil material may migrate onto adjacent streets or properties or into Elliott Bay. Deep soil mixing operations would not produce large vibrations.

Vibro-replacement may be performed in areas where vibrations would not substantially affect adjacent facilities. The gravel columns that are created using the vibro-replacement method are commonly referred to as stone columns. Stone columns, constructed of compacted gravel, are used to reinforce and densify the in situ soil, thereby reducing liquefaction potential. Stone column construction is accomplished by downhole vibratory methods using a vibratory probe that penetrates the ground, either under its own weight or aided by water jetting. Vibrations are generated close to the tip of the probe and emanate radially away from it. Gravel backfill is introduced in controlled lifts, either from the top through the annulus created by penetration of the probe (top feed), or through feeder tubes directed to the tip of the probe (bottom feed). Compaction of the gravel backfill by the vibratory probe forces the gravel radially into the surrounding in situ soil, forming a stone column that is tightly interlocked with the soil. The stone column and in situ soil form an integrated system with higher shear strength, lower compressibility, and lower susceptibility to liquefaction than the untreated soil.

Installation of stone columns could cause vibrations that could adversely affect buildings and utilities. In addition, settlement and lateral movements caused by the densification of the ground could affect adjacent structures. During installation, if soft soils are encountered, a large amount of gravel may be required before adequate interlocking with the soil could be obtained. If obstructions are encountered, progress of the installation of the stone columns could be impeded.

Fill Placement and Compaction

Several sections in the south portal area may include placement of fill. If backfilling and compacting operations are performed during wet weather, the stockpiled on-site materials may not achieve the desired degree of compaction. Improperly compacted fills could settle over time. Placement and compaction of fill materials adjacent to existing walls or structures could cause damage to the walls or structures because of the fill and compaction loading.

Construction effects of fill placement also can include instability during placement if the fill is placed over soft soil. Preliminary analyses indicate that fill heights up to about 15 feet high would be stable under static loading conditions over the soft and loose soils encountered in the south portal area. Based on the Bored Tunnel Alternative plans, the proposed fill embankments in the south portal area would be less than 15 feet high, or the fill would be placed on top of structural base slabs in the retained cuts; therefore, instability during construction is not anticipated.

Removal of Existing Structures

Several existing structures may need to be removed in the south portal area. This includes the Railroad Avenue ramps, existing utilities, and other small structures. If deep foundations are to be removed, vibration techniques used for removal may result in damage to adjacent structures and utilities, depending on the soil conditions and proximity. Excavations that are necessary for the removal of foundation elements would have similar effects as those discussed previously for excavations. If foundation elements remain in place and are located beneath new features, the presence of the foundation element could create a hard spot that would affect differential settlement of new foundations, fills, and utilities. If foundation elements are left in place, the slope stability of overlying fills may be improved, depending on the extent and type of underlying foundation elements.

Construction Vibrations

Several of the proposed construction methods could cause vibration, including pile driving, stone column installation, and other construction activities, as discussed further in Appendix F, Noise Discipline Report. Construction vibrations generally decrease exponentially with distance from the source. These vibrations could cause ground settlement and damage to utilities and structures.

6.1.2 Bored Tunnel

Section 5.2.2 describes the bored tunnel alignment. The 54-foot-diameter bored tunnel would be constructed using a TBM. The TBM would be launched at the south portal, and the boring process would proceed northward. Advancement of the TBM through the ground is accomplished using a combination of excavation at the leading edge (face) of the TBM and hydraulic jacks to push the TBM forward. As the TBM excavates the soil at the face and moves ahead, segmental concrete liner sections are erected to create a ring along the perimeter of the tunnel in the tail shield portion of the TBM. Hydraulic jacks push against the last ring installed to move the TBM forward. After the TBM has completed the push and the hydraulic jacks are retracted, the next liner ring is constructed.

Depending on the material through which the tunnel penetrates, the tunnel can be constructed with an open or closed face. Because the proposed bored tunnel would penetrate through a variety of soil types below the water table, and because resulting settlement could substantially affect the downtown Seattle area, a closed-face TBM would be used. With closed-face TBMs, the excavation at the face of the machine is performed with positive pressure acting on the excavation at the face of the TBM to prevent the soil at the face from moving.

Two types of TBMs are being considered to construct the bored tunnel: an earth pressure balance (EPB) machine or a slurry pressure balance (SPB) machine. Typically, SPB TBMs are more suitable for granular soils (e.g., sand and gravel), and EPB TBMs are more suitable for fine-grained clay and silt soils. Both types of soils are present along the proposed bored tunnel alignment. Recent modifications have allowed for more widespread use of both types of TBMs in more variable soil conditions. Both types of TBMs have the ability to control the face pressure to minimize ground loss.

The EPB machine allows the pressure in the tunnel face cavity to develop naturally by limiting the extraction of the soil and groundwater through a screw conveyor while the TBM is advanced and the soil is excavated. The pressure at the face is controlled by balancing the rate of advance of the TBM with the rate of discharge of the excavated material through the screw conveyor. Conditioners can be added to the excavation process at the face to improve workability of the excavated material, modify soil permeability, improve flow, and reduce friction. The excavated material exiting through the screw conveyor generally consists of wet, cohesive mud that has a toothpaste-like consistency. This excavated material is then transported via conveyors or muck cars to the starting point of the tunnel for transfer into trucks, rail cars, or barges for off-site disposal.

The SPB machine uses slurry to pressurize the face during excavation and to transport the cuttings. The slurry and excavated material is transported through pipes to a slurry separation plant located on the ground surface at the starting point of the tunnel. The slurry separation plant would likely be located on WSDOT property west of First Avenue S. in the south portal area. The slurry separation plant would typically consist of an arrangement of conveyors, pumps, centrifuges, filters, screens, and sumps. The slurry separation plant would process the spoils exiting the tunnel to remove the excavated soil suspended in the slurry so that the slurry can be recycled and used to further excavate the tunnel. After separation, the remaining wet soil spoils can be stockpiled or loaded into trucks, rail cars, or barges for off-site disposal.

Both types of TBMs can be constructed with grout pipes embedded in the tail of the shield to allow grout injection at the back of the TBM as it advances forward. This grout would fill the annular void that is theoretically present around a bolted tunnel liner ring, thus preventing the development of a void and subsequent propagation of ground loss to the surface. Sources of the void include the over-cut, the shield taper, steering losses, and the tail loss due to the difference in diameter between the shield and assembled liner segments. Over-cut is the difference in diameter between the rotating head of the TBM and the solid steel shield. Taper is the difference in diameter from the front to the back of the shield. Both over-cut and taper are purposely designed into the TBM as measures to reduce friction between the TBM and the ground by creating a void around the perimeter of the TBM (annular void). Steering losses occur as the TBM translates up or down or side to side, creating an oval void in the ground. These voids, if not filled or compensated by grout, would eventually become filled with soil, and this loss of ground into the void would propagate to the ground surface and could result in settlement.

To provide a stable cover and bored tunnel headwall at the south portal of the bored tunnel, ground improvement may be performed between S. King Street and S. Jackson Street, as described in Section 5.2.2. This ground improvement is a mitigation measure for potential soil loss and ground settlement over the south end of the tunnel. The soil in this area consists of loose fill with localized areas containing wood debris and other deleterious materials. Ground improvement may be performed in areas where the tunnel would pass beneath existing buildings and other structures (e.g., the existing viaduct).

Erosion and Sediment Transport

Effects of erosion and sediment transport for the bored tunnel would be less than for the south or north portal areas because most of the bored tunnel section is below ground and not exposed to surface precipitation or runoff. Excavated material (muck) that falls off of conveyors or out of muck cars can accumulate in the tunnel invert and be transported by construction equipment to areas outside of the tunnel. In addition, equipment working in areas where ground improvement is performed would result in some potential for erosion and sediment transport. These effects would be similar to but of smaller magnitude than those described for the south portal area in Section 6.1.1.

Existing Surface Features

Effects of construction equipment on existing pavements and utilities would be similar to those described for the south portal area in Section 6.1.1.

Stockpiles and Spoils Disposal

The volume of soil to be excavated from the bored tunnel alignment is about 808,000 cubic yards. Spoils associated with operation of the TBM would consist of soil cuttings mixed with water, conditioners, or slurry. If an EPB TBM is used, the excavated spoils would consist of mud with a toothpaste-like consistency. This material is not suitable for reuse in other areas of the Program and would be transported off site for disposal. Because of its consistency, it is unlikely that this material would be stockpiled long term. Some temporary stockpiling at the end of the conveyor system or muck train track could be required to facilitate the transport of the material off site. If these temporary stockpiles are not suitably protected, surface water erosion could result in deposition of sediment onto adjacent properties, streets, and stormwater drains, or into Elliott Bay. Transport and disposal of spoils are further discussed in Appendix B, Alternatives Description and Construction Methods Discipline Report.

If an SPB TBM is used, the mixture of slurry and soil would be processed prior to disposal to remove the slurry and the water. After the separation process, the remaining soil would be stockpiled on site or transported off site. Some of these spoils may contain soil that could be used as fill in other areas of the Program. Structural fill may be stored in stockpiles at staging areas located along the study area, as further discussed in Appendix B, Alternatives Description and Construction Methods Discipline Report. The effects of these stockpiles would be similar to those discussed for the south portal area in Section 6.1.1.

Foundations

If an SPB TBM is selected, a slurry plant would be constructed in the south portal area. Foundations for the slurry plant would likely require deep foundations because the subsurface conditions are poor. Earth- and groundwater-related effects of deep foundations would be similar to those described in Section 6.1.1 for the south portal area.

Tunnel Boring

The primary effect of tunnel boring would be ground loss at the tunnel face and around the tail shield. Ground loss at the tunnel face and around the tail shield can migrate to the ground surface and cause settlement of buildings and other structures. For this project, ground losses are assumed to be about 0.5 percent of the excavated tunnel volume, assuming good workmanship during tunnel construction. However, if soil conditions are loose, workmanship is poor, or abrupt changes in ground behavior are experienced, greater ground losses may occur.

Ground loss at the tunnel face and around the tail shield could translate up through the soil above the tunnel and result in settlement at the ground surface. The shape of the surface settlement area typically resembles an inverted normal probability curve with maximum settlements over the tunnel centerline and a total width of about 1.5 to 2 times the tunnel depth. In areas where the tunnel is less than 100 feet from the ground surface, the settlement area can be narrower with larger settlements over the tunnel centerline. The shape and magnitude of the settlement area depend on the size and depth of the tunnel, the tunneling methods and workmanship used, and the subsurface conditions. In general, settlement over the centerline of the tunnel is largest when the depth of soil cover is smallest. Settlement caused by ground loss during tunnel boring could affect existing buildings, utilities, roadways, the existing viaduct, and other surface features.

The TBM would penetrate through a variety of soil types ranging from clay to gravel. Many of these soil layers are highly interbedded. Improper control of the stability of these intermixed soils at the tunnel face could lead to greater ground loss in the sand and gravel soils than the clay and silt soils. This type of ground loss can migrate to the ground surface over time and create ground settlement.

The bored tunnel would also pass below the EBI and BNSF tunnels, as described in Section 5.2.2. Insufficient face pressure when the TBM passes beneath these structures could cause excessive ground loss and potential damage to these tunnels. Excessive face pressure at these locations could also cause damage and leakage of slurry or material into the tunnels.

Portal Break-Out and Break-In

The start and end points of the tunnel coincide with locations where the TBM would be operating closest to the ground surface and where the TBM would need to start boring (break-out) through the launch area (south portal) or end boring (break-in) into the receiving area (north portal). At both locations, the bored tunnel would penetrate through a headwall at the end of the excavations for the launch or receiving areas. Ground loss and resulting settlement at the ground surface could occur if adequate measures have not been taken in advance to control the inflow of groundwater and soil at the seal between the TBM and the structural headwall. Because of the large diameter of the TBM and shallow depth below the ground surface, the strength of the existing soil above the TBM may not be sufficient to allow for control of the face pressure. If an SPB TBM is used, the pressure of the slurry cannot be too high or slurry may escape to the ground surface or exert excessive loads on the structural headwall. The slurry pressure also cannot be too low or the soil may collapse into the face, resulting in ground loss and corresponding surface settlement. It is common practice to improve the ground conditions around the headwall and break-out/break-in zones to minimize these concerns.

The bored tunnel headwall at the ends of the excavations for both the launch and receiving areas would require about 56 feet of unsupported height and width to allow an opening for the TBM. Traditional steel tiebacks cannot be used to support the headwall because the TBM cannot penetrate through tiebacks. However, fiberglass reinforcement or other nonmetallic materials may be appropriate substitutes. External shoring of the headwall may be used, as long as it does not interfere with the exit or entry of the TBM.

Ground improvement may be required at the bored tunnel headwall locations to provide increased soil strength and resulting decreased ground loads on the headwall. If jet grouting is used, effects would be similar to those discussed for the south portal area in Section 6.1.1.

Construction Vibrations

The proposed construction methods for the bored tunnel could cause vibration, although impact vibrations are not anticipated. Vibrations would generally be due to drilling of retaining wall systems or tunnel boring. These vibrations would be highest near the bored tunnel portals where the tunnel is close to the ground surface. As the tunnel extends deeper below the ground surface, the vibrations would diminish. This is discussed further in Appendix F, Noise Discipline Report. Construction vibrations generally decrease exponentially with distance from the source. Effects of vibration on existing facilities would be similar to those discussed for the south portal area in Section 6.1.1.

Ground Improvement

Ground improvement may be performed along the tunnel alignment to stabilize soft soils around the tunnel and mitigate potential ground loss. Ground improvement along the bored tunnel is anticipated to consist of jet grouting or compensation grouting. Section 6.1.1 presents the effects related to installation of jet grouting.

Compensation grouting may be performed through the tunnel liner to mitigate ground loss during tunneling, or beneath structures where settlement is anticipated or detected during construction of the bored tunnel. Grout is injected into the ground beneath the structure foundations and a grout bulb is formed. The grout displaces the soil and has the potential for uplifting the foundation and restoring ground support. For sensitive structures where settlement is anticipated, grout pipes could be installed prior to construction. Settlement monitoring could be performed as construction progresses, and then, if ground settlement is detected, the pipes could be used to inject the grout and maintain the structure alignment. If the grout is not installed in time, excessive settlement of the structure could occur. Also, if the grout injection pressure is not carefully controlled, excessive uplift or lateral pressure against the foundations could cause damage to the structure. In some cases the compensation grouting may be performed from inside of large-diameter drilled shafts. Section 6.1.1 discusses the effects due to drilled shaft installation.

6.1.3 North Portal Area

Section 5.2.3 includes a description of the north portal area. Earthwork for the north portal area primarily includes construction of large retained excavations for the cut-and-cover tunnels, retained cut sections, and tunnel operations building excavation. Along the cut-and-cover section of the north portal area, the retained excavation would be filled in after the roadway structure is constructed. At the bored tunnel portal near Thomas Street, the retained excavation would be about 70 feet wide and 90 feet deep to receive the TBM at the completion of tunnel boring. Extending toward the north, the excavation would become shallower. The northbound and southbound lanes would unbraid until the north end of the cut-and-cover tunnel near Harrison Street. At this point, the footprint of both roadways would be about 250 feet wide, and the depth of the excavation would be about 50 feet. From this point northward, two separate excavations may be performed to construct the side-by-side retained cut roadways.

Following construction of the SR 99 roadway and ramps, the cut-and-cover portion of the excavations would be filled in to restore the grade. The surface streets above the SR 99 roadway area would then be reconnected at Harrison Street, Thomas Street, and John Street. Another surface street connection would be made along or near Sixth Avenue N., which would connect the traffic flow from the new ramps to the depressed roadway along Mercer Street. The existing retained cut along Mercer Street would be widened to accommodate two additional lanes of traffic. Construction of this connection and the roadway widening would require demolition of portions of the existing retaining walls at Mercer and Broad Streets.

The tunnel operations building, located east of Sixth Avenue N. between Thomas and Harrison Streets, would have underground levels extending as deep as 80 feet below the ground surface. Other earthwork in the north portal area includes construction of foundations for structures, grading for roadways, trenching for utilities, placement and compaction of fill, and removal of existing retaining walls and other subsurface structures. In shallow excavation areas such as utility trenches, temporary shoring may be used to provide excavation support. Ground improvement may be performed in some areas to stabilize existing soft and loose soils, reduce perched groundwater flow, and mitigate potential future liquefaction. The earthwork would also generate the need for stockpiles and spoils handling and disposal.

The subsurface soil deposits in the north portal area are generally more competent than those in the south portal area. In addition, the regional water table is located more than 60 feet below the ground surface. Earth- and groundwater-related effects of the north portal area construction would be similar to but of smaller magnitude than those in the south portal area because of the better subsurface soil and groundwater conditions.

Erosion and Sediment Transport

All areas beneath fills, pavements, foundations, and other structures would be cleared of all existing pavement, vegetation, and debris and stripped of organic soils. The debris resulting from these clearing activities would be removed from the area. The prepared ground surface would have high erosion potential if exposed during the rainy season or in the presence of surface water. Any areas that are disturbed during construction would be subject to increased erosion if proper control measures are not followed. The surface soil could erode and drain into stormwater drains, into Lake Union, or onto adjacent properties or streets. Other earth- and groundwater-related construction effects related to erosion and sediment transport would be similar to those described for the south portal area in Section 6.1.1. Additional effects related to surface water and erosion are also included in Appendix O, Surface Water Discipline Report.

Existing Surface Features

Effects of construction equipment on existing pavements and utilities would be similar to those described for the south portal area in Section 6.1.1.

Temporary and Permanent Retaining Walls

Various retaining wall types may be selected to retain soils for the cut-and-cover tunnels, retained cut sections, and other temporary and permanent excavations. Retaining wall types that may be used in the north portal area include soldier pile and lagging walls, soil nail walls, cantilever CIP concrete walls, diaphragm walls, and gravity walls. Earth- and groundwater-related effects of retaining wall construction would be similar to those described for the south portal area in Section 6.1.1. If soil nail walls or other passive retaining wall systems are used in the north portal area, ground movement behind the wall could cause damage to adjacent structures and utilities.

Excavations and Dewatering

Excavations would be made for relocation of utilities, construction of foundations, and excavation for retained cuts, cut-and-cover tunnels, and the tunnel operations building. Conventional equipment, including excavators and backhoes, would likely be used to perform the excavation. Some excavation may require extra equipment and actions in areas with very dense glacially overridden deposits. The soils or soils mixed with rock would need to be broken up using a mechanical ripper (tine or fork) mounted on a backhoe or other excavation equipment. Earth- and groundwater-related effects of excavation would be similar to but of smaller magnitude than those described for the south portal area in Section 6.1.1 because the subsurface soil and groundwater conditions in the north portal area are generally better than conditions in the south portal area.

Extensive dewatering is not anticipated for the proposed excavations in the north portal area because the regional water table is located more than 60 feet below the ground surface. Perched seepage zones may exist above the water table; however, this seepage can typically be controlled by sumps and pumps in the excavations. Improper maintenance of sumps and pumps could result in buildup of water in the excavations, which could increase the potential for erosion and sediment transport onto adjacent roadways.

Stockpiles and Spoils Disposal

Based on the current level of Bored Tunnel Alternative design, about 210,000 to 240,000 cubic yards of spoils would be generated from the proposed excavations in the north portal area. Earth- and groundwater-related effects of stockpiles and spoils disposal would be similar to those described for the south portal area in Section 6.1.1.

Foundations

Foundations for the tunnel operations building in the north portal area would consist of shallow or deep foundations. Selection of the appropriate foundation types to support the building would depend on subsurface conditions underlying the structures, site constraints, and constructability. Earth- and groundwater-related effects of drilled shafts or driven pile construction would be similar to those described in Section 6.1.1 for the south portal area.

Excavations for shallow spread footing foundations and pile caps may affect adjacent structures. Effects would be similar to those discussed previously in the section "Excavations and Dewatering."

Fill Placement and Compaction

Several sections in the north portal area would include placement of fill. Earth- and groundwater-related effects of fill placement and compaction would be similar to those described in Section 6.1.1 for the south portal area.

Removal of Existing Structures

Several existing retaining walls may need to be partially removed in the north portal area to provide access for the roadway connections, ramps, and temporary detour routes. In addition, several existing structures would be demolished. In areas where only portions of existing retaining walls are to be removed, the stability of the existing retaining wall could be affected if suitable support is not provided in the removal area. This could result in adverse horizontal movement of the existing retaining wall and subsequent settlement of utilities and structures behind the walls.

Construction Vibrations

Several of the proposed construction methods could cause vibrations similar to those in the south portal area. Since the soil conditions in the north portal area are generally more competent, earth- and groundwater-related effects due to construction vibrations would be similar to but of smaller magnitude than those described for the south portal area in Section 6.1.1.

6.1.4 Viaduct Removal

The Bored Tunnel Alternative includes removing and relocating the utilities on the existing viaduct and demolishing the viaduct. Shallow excavations (estimated depth of 5 feet) would be performed to remove existing viaduct foundation caps. The underlying foundation piles would not be removed. Due to the shallow depth of these excavations, no effect on the earth or groundwater environment is anticipated. Construction effects related to removal of the viaduct would be related to erosion and sediment transport, stockpiles, spoils disposal, and construction vibrations, as well as excavations for the relocated utilities.

Erosion and Sediment Transport

Demolition of the viaduct and removal of foundation caps and utilities below the viaduct would result in ground disturbance that would increase the erosion potential of the soil. Effects related to erosion and sediment transport would be similar to those described for the south portal area in Section 6.1.1. Additional effects related to surface water and erosion are also included in Appendix O, Surface Water Discipline Report.

Stockpiles and Spoils Disposal

The removal of the existing viaduct would generate spoils consisting of soil, concrete rubble, and steel. Approximately 107,000 cubic yards of debris would be generated. Some of the debris may be stockpiled on site prior to transport to an appropriate disposal location. Some of the debris may be used to fill in the Battery Street Tunnel (see Section 6.1.5). Earth- and groundwater-related effects of stockpiles would be similar to those described for the south portal area in Section 6.1.1.

Construction Vibrations

Demolition of the existing viaduct would likely be performed using hoe-rams and other vibratory equipment. Additional vibrations could be caused as portions of the viaduct structure fall onto the ground. This is discussed further in Appendix F, Noise Discipline Report. Construction vibrations generally decrease exponentially with distance from the source. These vibrations could cause ground settlement and damage to utilities and structures.

Excavations and Dewatering

Excavations would be made for relocation of utilities. The location and depth of the excavations has not yet been determined, but they would be adjacent to the existing structure and could be several feet deep. Conventional equipment, including excavators and backhoes, would likely be used to perform the excavations. Earth- and groundwater-related effects of excavation would be similar to but of much smaller magnitude than those described for the south portal area in Section 6.1.1.

6.1.5 Battery Street Tunnel Decommissioning

The Battery Street Tunnel would be decommissioned as part of the Bored Tunnel Alternative. One option for decommissioning includes filling the Battery Street Tunnel partially with the concrete debris generated from the viaduct demolition. The remainder of the empty space in the tunnel would then be filled with concrete slurry to provide a continuous backfill. The only earth- and groundwater-related effects associated with the Battery Street Tunnel decommissioning would be those related to sediment transport by trucks transporting debris into and out of the tunnel. The sediment could be deposited onto existing roadways along the haul routes if appropriate BMPs are not implemented.

6.2 Construction Mitigation

Mitigation measures for the construction effects are based on the site information and standard design and construction procedures in use at the time of this report. The construction of the Bored Tunnel Alternative would be observed by experienced engineers or technicians who would observe the construction activities and provide recommendations to minimize the earth- and groundwater-related effects. Most of the earth- and groundwater-related effects can be mitigated through the use of BMPs and good workmanship during construction.

6.2.1 Mitigation Measures Common to All Areas

Many of the construction effects identified in Section 6.1 are common to all areas of the Bored Tunnel Alternative. This section discusses mitigation measures for these effects.

Exploration and Design Approach

The Bored Tunnel Alternative will be designed by experienced engineers based on the available subsurface information, design procedures and criteria approved by WSDOT and the City of Seattle, and the existing site conditions. To adequately define subsurface conditions, additional subsurface data are being collected along the bored tunnel alignment, as described in Section 5.3.1. This would partially mitigate the potential for unknown subsurface conditions to affect the construction of the Bored Tunnel Alternative.

Erosion and Sediment Transport

Construction BMPs are required by WSDOT and City of Seattle for major projects, including construction staging barrier berms, filter fabric fences, temporary sediment detention basins, and use of slope coverings to contain sediment on site. These BMPs would be effective in protecting water resources and reducing erosion from the construction areas. Erosion control measures suitable to the site conditions will be included as part of the design. More detailed information regarding BMPs is included in Appendix O, Surface Water Discipline Report. Temporary erosion and sediment control (TESC) plans will be prepared for approval in accordance with BMPs included in the current City of Seattle Stormwater, Grading, and Drainage Control Code (Ordinance 119965) and the WSDOT *Highway Runoff Manual* (WSDOT 2008a), whichever has more stringent requirements.

Erosion control measures include vegetative and structural controls. Structural controls would primarily be used because the corridor of the Bored Tunnel Alternative is highly developed. Structural controls consist of artificial means of preventing sediment from leaving the construction area. Proposed mitigation measures would comply with stormwater design and treatment procedures in the current version of the WSDOT *Highway Runoff Manual* (WSDOT 2008a). Such procedures follow the National Pollutant Discharge Elimination System (NPDES) guidelines administered by Ecology. WSDOT guidelines require approval of a stormwater site plan and a TESC plan prior to construction. The stormwater design should also satisfy the City of Seattle's Stormwater, Grading, and Drainage Control Code (Ordinance 119965). The erosion and sediment control measures should be in place before any clearing, grading, or construction.

Existing Surface Features

Construction traffic should be routed onto roadways that are capable of handling heavy loading. In areas where construction traffic cannot be rerouted onto suitable roadways, existing roadways would either have to be improved prior to construction or repaired following construction. Alternatively, smaller and lighter construction equipment could be used in some areas. Since the Bored Tunnel Alternative is located in urban Seattle, it is likely that many roads are already designed to accommodate truck loading. To reduce dust during hauling, the loads should be covered during transport.

For utilities that are located within construction areas, relocation could be considered. If relocation is not feasible, monitoring of the utilities during construction should be performed. This could be done by performing survey monitoring at the ground surface. For more critical utilities, potholing or trenching may be required to daylight a portion of the utility so that monitoring equipment can be placed on the utility pipes.

Temporary and Permanent Retaining Walls

Proper construction procedures should be used to install permanent and temporary retaining walls for excavations, cuts into slopes, foundation preparation, retained cut sections, cut-and-cover tunnels, and building excavations. For all of the potential wall types that may be used, proper design and construction procedures would mitigate potential settlement and ground movement adjacent to the wall. The wall depths and bracing configurations should be designed to limit wall movement and support all earth, groundwater, and surcharge loads.

In areas where additional support is needed for a wall and the wall height cannot be reduced, the use of bracing systems such as internal bracing, tiebacks, or soil nails (north portal area only) could be considered. Prior to installation of tiebacks or soil nails, a careful survey of adjacent structures, utilities, and foundations should be performed. If utilities or foundations are present, tieback or nail configurations can be altered or internal bracing or a cantilever wall system used in that area. Additional mitigation measures include minimizing unsupported wall heights; controlling ground losses; and timely installation of suitable bracing, tiebacks, or soil nails.

Temporary excavations should be adequately shored to mitigate potential sloughing of soils and lateral movement or settlement of nearby existing roadways, railways, structures, and utilities. The shoring system should consider the loads applied due to construction equipment working behind the top of the excavation and any other surcharge loads. Stockpiles should be placed a minimum of twice the excavation depth away from the top of the excavation.

Appropriate selection of wall type can also mitigate ground movement, seepage, and other identified effects. Diaphragm walls are generally more effective at preventing groundwater inflow than other wall types (e.g., soldier pile or sheet pile walls). Diaphragm walls can consist of secant pile walls, tangent pile walls, deep soil mixing walls, or slurry walls. Slurry walls and deep soil mixing walls can provide better groundwater cutoff because they are relatively continuous with depth. If the alignment of secant pile or tangent pile walls is not carefully controlled, gaps between the piles can occur at depth, which would reduce the effectiveness of the water cutoff. However, in areas with potential debris and very dense soils, installation of slurry walls may be difficult, and installation of deep soil mixing walls may result in weak walls zones. In areas with these subsurface conditions, secant pile or tangent pile walls would provide a better wall system.

Excavations

Excavations would be needed for construction of foundation elements, retained cuts, cut-and-cover tunnels, and the excavations for the tunnel operations buildings. Conventional equipment, including excavators and backhoes, would likely be used to perform the excavation.

Temporary excavations should be adequately shored to mitigate potential sloughing of soils and lateral movement or settlement of nearby existing roadways, railways, structures, and utilities. The shoring system should consider the loads applied due to construction equipment working behind the top of the excavation and any other surcharge loads. Stockpiles should be placed a minimum of twice the excavation depth away from the top of the excavation. The use of temporary tiebacks or other bracing would also reduce the potential for ground movement adjacent to deep excavations. The shoring system should consider the loads applied due to construction equipment working behind the top of the excavation and any other surcharge loads.

Vibratory methods for sheet pile installation would not be allowed in areas where vibrations may affect adjacent facilities. Depending on the soil conditions, the sheet piles could be pushed into the ground without vibration. If the soil conditions are too dense, predrilling could be performed to prepare holes for the sheet piles, or alternative shoring methods could be considered.

Stockpiles and Spoils Disposal

Construction BMPs discussed in Appendix O, Surface Water Discipline Report, would mitigate some of the construction effects related to spoils disposal. Additional mitigation measures for spoils disposal are included in Appendix Q, Hazardous Materials Discipline Report.

Stockpiles should not be placed directly over utilities or pavements that should not be damaged. Alternatively, stockpile heights could be limited so that excessive settlement or damage of underlying utilities or pavements does not occur. The stockpiles should be covered with plastic to mitigate erosion due to surface water and rain.

Construction Vibrations

Several of the proposed construction methods could cause vibration resulting in ground settlement and damage to utilities and structures. The actual vibration and settlement levels that occur as a result of construction depend on many factors, including subsurface conditions, construction methods, and quality of the work. Allowable vibration levels would be established for critical structures and utilities near the construction activities. Preconstruction surveys will be performed to establish a baseline. During construction, monitoring of vibrations could be performed to confirm that allowable vibration levels are not being exceeded. In areas where vibration cannot be tolerated, consideration should be given to construction methods that limit vibration.

6.2.2 South Portal Area

Many mitigation measures for the south portal area are common to all areas and are presented in Section 6.2.1, including measures related to erosion and sediment transport, existing surface features, temporary retaining walls, excavations and dewatering, stockpiles and spoils disposal, and construction vibrations. This section presents other mitigation measures for the earth- and groundwater-related construction effects in the south portal area.

Excavations and Dewatering

In areas where excavations may extend below the water table, erosion and instability of excavation sides may result. The contractor should control the entry of water into excavations. Dewatering of soils within and below excavations may be performed to control inflow, remove water from excavations, and reduce hydraulic forces that could destabilize excavations. This could be done by using sumps or well points in small excavations and dewatering wells in deep excavations. Dewatering would be performed until construction of the subsurface structures is completed. Handling and disposing of contaminated and clean water is discussed in Appendix O, Surface Water Discipline Report.

Dewatering systems should consider minimizing the drawdown of the water table outside of the excavation in areas where adjacent structures may be affected. Mitigation measures include the use of groundwater recharge wells, dewatering in small sections, or use of barriers (e.g., sheet piles, diaphragm walls) to isolate the water table within the excavation. Dewatering and recharge wells should be carefully constructed to the specified design of the well depth, length, screen, and filter pack. Proper maintenance of the wells should be performed to ensure that they are working as designed. Monitoring of the water table and settlement outside of the excavation should be performed to confirm that the dewatering system is working as designed.

Diaphragm Walls

Diaphragm walls would be used to support the sides of the deep retained cuts, cut-and-cover tunnels, and tunnel operations building excavation in the south portal area, as described in Section 6.1.1. The use of diaphragm walls would mitigate groundwater inflow into the excavations. Proper construction procedures should be followed to mitigate potential settlement and lateral movement of the ground surface behind the walls.

In areas where wood or other debris is present in the subsurface, pretrenching would be required prior to slurry wall installation to remove the wood. The effects of pretrenching would be the same as those for excavations (see Section 6.1.1), and would have the same mitigation measures (see Section 6.2.1). For secant or tangent pile walls, the walls would be installed with drilled shaft equipment. To penetrate through the wood debris, an oscillator or rotator casing could be used to cut through the wood and install the piles. If discontinuities are noted in the walls as excavation proceeds, postgrouting could be performed to seal potential leaks and strengthen the wall section.

Foundations

Drilled shafts may be used to support structures and construct secant or tangent pile walls. Slurry and/or casing can be used to mitigate potential caving of the side walls in the drilled hole. Casing can be installed by twisting, driving, or vibrating the casing into the ground. Vibration or driving methods should not be used in areas that are close to adjacent structures. The use of slurry could also be used to mitigate potential heave and erosion that could be caused by groundwater pressures in sandy soils.

Pile driving may be required for foundation and sheet pile installation. Preconstruction surveys of existing structures and vibration monitoring during sheet pile installation may be required to monitor potential damage to adjacent sensitive structures. With some installation methods, adjustments in the hammer size, frequency, or energy can be made to reduce vibrations. Other methods that may reduce vibrations include predrilling or using vibratory hammers where the vibration frequency can be controlled.

Ground Improvement

Ground improvement should be performed by contractors with experience in the selected ground improvement technique. During any type of ground improvement installation, monitoring of adjacent utilities or structures should be performed. In general, jet grouting and deep soil mixing do not cause vibrations. Spoils generated from ground improvement activities should be properly contained by constructing berms or other barriers around the construction area. Proper containment would mitigate migration of spoil material onto adjacent streets or properties.

The jet grouting process should be properly controlled so that gaps in the improved area do not occur when soils of low erodibility are encountered. In addition, shadowing could occur when obstructions such as wood debris are encountered, resulting in gaps in the improved zone. The spacing of jet grout columns may have to be decreased in areas where these soils or obstructions are encountered. The jet grouting spacing should be close enough so that obstructions are encapsulated in the jet grout. Alternatively, pretrenching could be performed to remove obstructions. The jet grouting pressure near the surface should be carefully controlled to avoid applying excessive pressure on or leakage of jet grout into adjacent utilities or structures. Jet grouting spacing and pressure may have to be decreased near critical utilities or structures.

During deep soil mixing operations, care should be taken to avoid rapid advance or withdrawal of the augers and inadequate control of grout pumping rates. Deep soil mixing should not be performed immediately adjacent to existing utilities or structures because temporary loosening of the soil could cause settlement. If obstructions are encountered, jet grouting could be considered to extend the improvement to a deeper depth or a larger plan area. Utilities or other settlement-sensitive structures should be monitored during deep soil mixing activities. Settlement could be mitigated by installing shoring walls adjacent to utilities. These shoring walls would provide a barrier between the utilities and the deep soil mixing activities.

Vibro-replacement (stone column) methods would not be used in areas where vibrations and settlement could substantially affect adjacent facilities. Alternative methods of ground improvement such as jet grouting or deep soil mixing should be considered.

Compensation grout pipes may be installed around sensitive structures that are anticipated to settle during construction. Settlement monitoring should be performed at frequent intervals as construction progresses. If ground loss around the advancing tunnel or settlement is detected, compensation grout should be injected into the ground in a timely manner to maintain ground support under the structure and, if needed and feasible, uplift the structure and restore ground loss. Grout injection may be performed through the tunnel liner; from shafts installed adjacent to buildings; or from the ground surface. The grout pressure should be carefully monitored and controlled to avoid exceeding the strength of the building foundations and prevent uplifting the building higher than necessary.

Fill Placement and Compaction

If soft soils are present in the fill areas, overexcavation of the soft soils, use of geotextiles to bridge soft soils and strengthen fill zones, and use of lightweight fills should be considered. Fills should not be placed adjacent to walls or other settlement-sensitive structures unless the structures can accommodate the increased pressures due to the placement and compaction of the fill. Suitable structural fill should be used to construct the fills, as described in Section 5.3.2. The material should be compacted to the compaction criteria required by WSDOT. If fill placement and compaction is properly controlled and monitored, the identified construction effects would be mitigated.

Removal of Existing Structures

The Bored Tunnel Alternative includes removal of existing structures that may have various types of foundation elements. If deep foundations are to be removed, vibratory techniques should only be used in areas where adjacent structures or utilities would not be substantially affected. Vibration monitoring could be performed to confirm that tolerances are not being exceeded. Nonvibratory techniques (e.g., excavation of the foundation element) should be used in areas where adjacent utilities or structures cannot tolerate vibration or settlement. Excavations that are necessary for the removal of foundation elements would have similar effects as those discussed previously for excavations.

If foundations are left in place, they may result in a stress concentration (hard spot) beneath new facilities. This could be partially mitigated by excavating a portion of the upper part of the foundation element and placing material to diffuse the effect of the hard spot. Alternatively, the new facility could be designed to consider the presence of the potential hard spots. If foundation elements are left in place, the slope stability of overlying facilities may be improved depending on the extent and type of underlying foundation elements.

6.2.3 Bored Tunnel

Section 6.2.1 presents mitigation measures for the bored tunnel related to erosion and sediment transport, existing surface features, temporary retaining walls, excavations and dewatering, stockpiles and spoils disposal, and construction vibrations. This section presents other mitigation measures for the earth- and groundwater-related construction effects along the bored tunnel.

Foundations

If an SPB TBM is selected to construct the tunnel, a slurry plant, likely supported by deep foundations, would be constructed in the south portal area. Mitigation for effects caused by foundation installation would be similar to those described in Section 6.2.2 for the south portal area.

Tunnel Boring

The primary effect identified for boring of the tunnel would be excessive ground loss and resulting ground settlement. This can be mitigated in general through the use of prescriptive specifications that require the appropriate means and methods for controlling and monitoring the TBM and controlling the anticipated ground behavior and groundwater conditions. Ground loss typically occurs at the face and around the perimeter of the TBM. Ground loss can be mitigated by maintaining proper pressure at the face of the TBM. Typically the pressure should equal the pressure exerted by the overlying soil plus an additional percentage to account for groundwater pressure and other stress relief in the soil. Since a closed-face TBM does not allow for visual confirmation of the soil prior to excavation, field explorations are being performed along the tunnel alignment (see Section 5.3.1) to provide soil information for design and operation of the TBM. The face pressures and ground volume excavated would be monitored through a series of instruments in the TBM and in the ground above and near the TBM so that careful control of the face and potential ground loss can be achieved.

Critical structures and utilities likely to be affected by tunneling-induced settlement should be inspected prior to construction to evaluate their existing condition and potential for damage due to tunneling. Instrumentation should be installed to monitor ground movements on and below the ground surface during construction. In areas where the tunnel alignment crosses under settlement-sensitive structures or utilities, ground improvement can be used to presupport the structure or utility in advance of construction. Alternatively, grout pipes could be installed and then, if ground movement is detected by instrumentation or surveys, grout can be injected to uplift the building foundation (compensation grouting). Underpinning or stiffening of settlement-sensitive structures could also be performed.

Ground loss can also occur due to closure of the annulus between the TBM and the tail shield and tunnel liner. To mitigate ground loosening around the tail shield and liner and potential migration of voids to the ground surface, tail shield/backfill grouting behind the liner segments should be performed as soon as possible after the TBM passes. As discussed in Section 6.1.2, modern TBM designs typically include embedded grout pipes in the tail of the shield to allow injection of grout immediately at the back of the TBM as it advances to compensate for the annular void that develops from over-cut, shield taper, steering losses, and the tail loss.

Portal Break-Out and Break-In

The bored tunnel headwalls at the portals would likely consist of secant pile walls or other concrete walls that can be bored through by the TBM. Any reinforcement used in these walls would need to be synthetic (e.g., fiberglass) so that the TBM can penetrate through the headwall. The soils above the tunnel at the break-out and break-in points can be improved (e.g., by jet grouting) so that they have increased strength to maintain a stable soil cover. Additional tension capacity could be obtained by installing fiberglass face bolts or similar synthetic tiebacks. The face pressure in the TBM at the launch and receiving areas would be reduced to prevent heave of the ground surface or blowout of the headwall. Ground improvement or postgrouting would be required to mitigate ground loss at these locations.

The bored tunnel headwall at the end of the excavation in both the launch and receiving areas would require about 56 feet of unsupported height and width to allow for an opening for the TBM. To provide a stable headwall, stiff retaining wall systems may be required if no other support is provided. External bracing would have to be situated so that it does not interfere with the exit or entry of the TBM.

A seal at the bored tunnel headwall can mitigate ground loss during shaft break-out and break-in by preventing groundwater and soil flow in the annular gap between the TBM shield and headwall. Ground improvement may be performed between about S. King Street and S. Main Street to improve the soil conditions above the tunnel. The purpose of the ground improvement would be to provide additional soil strength above the tunnel launching and receiving areas, to lower the earth pressures acting on the headwalls, and to mitigate ground loss. The ground improvement should extend a sufficient distance such that several permanent lining rings are grouted in place within the treated ground before the TBM breaks into either virgin ground at the south portal or into free air at the north portal. Mitigation measures associated with jet grouting would be the same as those presented in Section 6.2.2.

6.2.4 North Portal Area

Many mitigation measures for the north portal area are common to all areas and are presented in Section 6.2.1, including measures related to erosion and sediment transport, existing surface features, temporary retaining walls, excavations and dewatering, stockpiles and spoils disposal, and construction vibrations. This section presents other mitigation measures for the earth- and groundwater-related construction effects in the north portal area.

Temporary and Permanent Retaining Walls

In areas where temporary or permanent retaining walls are located next to existing utilities, structures, or other settlement-sensitive facilities, the retaining walls would be designed to be rigid walls so that ground movement adjacent to the wall is mitigated. Wall types that are not rigid include soil nail walls and unbraced soldier pile and lagging or sheet pile walls. A diaphragm wall or a braced shoring system would likely be used for these areas to mitigate ground movement and potential damage to adjacent features. Mitigation measures for construction of these walls types would be the same as those presented in Section 6.2.2 for the south portal area.

Excavations and Dewatering

In general, the subsurface soil conditions in the north portal area are more competent than conditions in the south portal area. Also, extensive dewatering is not anticipated for the proposed excavations because the water table is located more than 50 feet below the ground surface. Mitigation measures associated with excavations would be similar to those presented in Section 6.2.2 for the south portal area. For control of water seepage into excavations, sumps or pumps could be placed in the excavation to control water. Alternatively, watertight shoring could be used to prevent perched water from entering the explorations.

Foundations

Foundations for the tunnel operations building in the north portal area would consist of shallow or deep foundations. Mitigation measures related to the effects of construction of deep foundations would be similar to those presented in Section 6.2.2 for the south portal area. For shallow foundations, if soft subgrade soils are exposed in shallow excavations, potential mitigation measures include overexcavation and replacement with compacted structural fill, performing ground improvement, or using deep foundations. Sections 6.2.1 and 6.2.2 present mitigation measures for these alternative construction methods.

Fill Placement and Compaction

Several sections in the north portal area would include placement of fill to align roadways and restore surface grade. Mitigation for effects caused by fill placement and compaction would be similar to those described in Section 6.2.2 for the south portal area.

Removal of Existing Structures

Several existing retaining walls may need to be partially removed in the north portal area to provide access for the roadway connections, ramps, and temporary detour routes. The portions of the adjacent walls that are not removed could be reinforced by adding tieback elements or external bracing. Alternatively, the new retained cut that would intersect the existing retaining wall can be constructed prior to removing the existing wall section. The new retained cut structure can be structurally integrated into the existing wall prior to removing the wall section. These procedures should be performed using rigid wall systems to mitigate the ground movement and potential damage to adjacent facilities.

6.2.5 Viaduct Removal and Battery Street Tunnel Decommissioning

Section 6.2.1 presents mitigation measures for these features that are common to all areas.

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Chapter 7 CUMULATIVE EFFECTS

Cumulative effects are effects on the environment that result from the incremental impact of the proposed action when added to other past, present, or reasonable foreseeable future actions. The cumulative effects analysis focused on the combined effects of the Bored Tunnel Alternative and other roadway and non-roadway elements included in the Program. It also evaluated the combined effects of the Bored Tunnel Alternative, other Program elements, and other past, present, and reasonable foreseeable future projects that are anticipated to add to effects on earth, soil conditions, and groundwater in the study area.

7.1 Trends Leading to Present Earth Conditions

Large-scale earth-moving projects over the past 100 years in support of urban development and growth in the region, specifically within the Seattle area, have modified the landscape and created land where there was once Puget Sound and slight inclines where there were steep hills. This process of excavation, regrading and filling has shaped the downtown Seattle area and the Program area for residential and commercial development through leveling hills and filling depressions, meeting the development needs, such as the expansion of the waterfront terminals through filling tidelands. The region also gradually expanded the roadway systems and rail network to meet the new and greater transportation needs to move people and goods.

Seismic and other building code standards were developed to reduce the risk of catastrophic failure of these structures due to earth resources and conditions such as liquefaction, earthquakes, and subsidence.

Until the 1890s, Seattle relied on small, privately owned wells, springs, and distribution systems for its water supply (Seattle 2010). The City of Seattle began developing surface water drinking water sources in 1890 with the purchase of the Spring Hill and Union Water Companies. The City then developed the Cedar River watershed and opened the water system in 1901. The use of wells for drinking and industrial water purposes decreased after 1901, and today there are no longer any drinking water wells within the Program area. Groundwater use in the Program area is currently limited to emergency and industrial uses as the City of Seattle has a large municipal water system.

Groundwater elevations in the Program area vary depending on the topography, and flow tends to be in the direction of Elliott Bay, except in the north end. The direction of flow is likely the historic direction though the depth to groundwater is highly dependent on topography and soil grain size. Large earth-moving projects likely have affected groundwater depth and flow regimes in the Program area.

7.2 Effects From Other Roadway Elements of the Program

7.2.1 Alaskan Way Surface Street Improvements – S. King to Pike Street

The Program includes improvements to and realignment of the Alaskan Way surface street along the waterfront from S. King Street to Pike Street. After the existing viaduct is demolished, a four- to six-lane Alaskan Way surface street would be constructed approximately along the existing viaduct alignment. Since these improvements would not typically involve excavating below the ground surface, earth- and groundwater-related effects would be minimal. The roadway intersections with the downtown Seattle street grid would be signalized, which would require installation of signal poles supported by drilled shafts. Effects related to drilled shafts would be similar to those discussed for the south portal area in Section 6.1.1. Some utilities in the improvement area would require relocation, which would result in excavations and, depending on trench depth, dewatering. Effects related to these items would be similar to those discussed for the south portal area in Section 6.1.1.

7.2.2 Elliott/Western Connector – Pike Street to Battery Street

A new connecting structure would be constructed from Pike Street near Alaskan Way to Battery Street. This structure would consist of an elevated structure with retained fill, primarily at the south abutment near Pike Street. The elevated structure would cross over the existing BNSF railroad tracks and two existing pedestrian overpasses. This section discusses earth- and groundwater-related effects related to the connecting structure.

Foundations

Deep foundations, likely consisting of drilled shafts, would be used to support the elevated structure. Operational and construction effects related to drilled shafts would be similar to those described in Sections 5.2.1 and 6.1.1, respectively.

Fill Embankments

Retained fill embankments would be constructed at the base of the existing hill below the Pike Place Market to form the abutment area of the connecting structure. The soil conditions in this area consist of soft and loose deposits that may not provide sufficient support for the fill embankments. Depending on the configuration of the fill embankment, excessive settlement or lateral movement of the fill could occur as the fill is placed. The subsurface soil in this area may also liquefy during a seismic event, causing instability of the overlying fill embankment. Placement of the fill would also cause settlement of the existing ground surface and adjacent facilities. Section 6.1.1 includes other construction effects for fill placement.

Excavation and Retaining Walls

The construction of the connection structure may require excavation into the existing hillside north of Pike Street and above the BNSF railroad tracks. The existing slope in this area is considered a steep slope by the City of Seattle. The existing slopes consist of relatively dense, glacially overridden soils that have been weathered. Excavation into the slope may result in local instability, which could cause damage to adjacent facilities. Temporary or permanent retaining walls would be required in areas where excavation is required. The earth-related operational and construction effects of retaining walls would be similar to those presented for the north portal area in Sections 5.2.3 and 6.1.3, respectively.

Excavations may also be performed for installation of utilities and other subsurface facilities. Effects related to these items would be similar to those discussed for the north portal area in Section 6.1.3.

7.2.3 Mercer West Project – Fifth Avenue N. to Elliott Avenue

Mercer Street would be restriped and resignalized between Fifth Avenue N. and Second Avenue W. to create a two-way street with turn pockets. No earth- and groundwater-related effects are anticipated for this element.

7.3 Effects From Non-Roadway Elements of the Program

7.3.1 Elliott Bay Seawall Project

The Elliott Bay Seawall needs to be replaced to protect the shoreline along Elliott Bay, including Alaskan Way. It is at risk of failure due to seismic and storm events. The seawall currently extends from S. Washington Street in the south to Bay Street in the north, a distance of about 8,000 feet. The Elliott Bay Seawall Project limits extend from S. Washington Street in the south to Pine Street in the north (also known as the central seawall).

The existing Elliott Bay Seawall would be replaced likely using a combination of jet grouting and drilled shafts. Operational and construction effects related to drilled shafts are presented in Sections 5.2.1 and 6.1.1, respectively.

Operational and construction effects related to jet grouting are presented in Sections 5.2.1 and 6.1.1, respectively. In areas where extensive debris, such as logs and concrete, is present, some subsurface zones may not be adequately improved because of the presence of these non-erosive materials (shadowing effect). This could be mitigated by preexcavating and removing obstructions. Grout injected into the soil may also travel through open soil layers or through the seawall and enter Elliott Bay. This could be mitigated by carefully controlling the jet grout process or installing impermeable barriers adjacent to the seawall.

Some utilities along the seawall would require relocation to allow for seawall replacement. Relocation of utilities would require excavations and, depending on trench depth, dewatering. Effects related to these items would be similar to those discussed for the south portal area in Section 6.1.1.

7.3.2 Alaskan Way Promenade/Public Space

A new waterfront promenade would be constructed adjacent to the Alaskan Way Seawall and extending into the current alignment of Alaskan Way. Since these improvements would not typically involve excavating below the ground surface, earth- and groundwater-related effects would be minimal. Some utilities along the promenade would require relocation, which would result in excavations and, depending on trench depth, dewatering. Effects related to these items would be similar to those discussed for the south portal area in Section 6.1.1.

7.3.3 First Avenue Streetcar Evaluation

The First Avenue streetcar is currently proposed to run between Yesler Way and Republican Street along First Avenue. Construction of the streetcar evaluation would require utility protection and/or replacement. This would result in excavations and, depending on trench depth, dewatering. Effects related to these items would be similar to those discussed for the south portal area in Section 6.1.1.

7.3.4 Transit Enhancements

A variety of transit enhancements will be provided to support planned transportation improvements associated with the Program. These would include (1) the Delridge RapidRide line, (2) additional service hours on the West Seattle and Ballard RapidRide lines, (3) peak-hour express routes added to South Lake Union and Uptown/Lower Queen Anne, (4) changes to local bus service (such as realignments and a few additions to several West Seattle and northwest Seattle routes), (5) transit priority on S. Main and/or S. Washington Streets between Alaskan Way and Third Avenue, and (6) simplification of the electric trolley system. Additionally, northbound and southbound right-side transit lanes on SR 99 are assumed from just south of the Aurora Bridge to north of Aloha Street. No excavations are planned for these improvements; therefore, no earth- and groundwater-related effects are anticipated for this Program element.

7.4 Cumulative Effects of the Project and Other Program Elements

Cumulative effects on earth are generally related to the construction period when earth and groundwater would be altered or moved. No operational effects identified in this report are anticipated to contribute to a cumulative effect. Many of the construction effects identified herein would also not contribute to a cumulative effect because BMPs would be used during construction of the Bored Tunnel Alternative and other adjacent projects, as required by city and state regulations. The following construction effects may contribute to a cumulative effect on earth and groundwater:

- Construction dewatering for excavations may lower the water table. This could result in settlement of buildings and other adjacent facilities if recharge of the water table is not performed.
- Ground loss could occur during construction of the bored tunnel. This ground loss could lead to settlement at the ground surface, which would affect existing structures, utilities, and other facilities.

Two projects associated with the Program were determined to have potential cumulative effects on earth and groundwater based on their location and planned construction:

- First Avenue Streetcar Evaluation
- S. Holgate Street to S. King Street Viaduct Replacement Project

The other projects in the Program were determined to have no potential cumulative effects because of their distance from the bored tunnel alignment (greater than 200 feet), or their construction schedule (construction occurs before or after construction of the Bored Tunnel Alternative).

7.5 Cumulative Effects of the Project, Other Program Elements, and Other Actions

The effects of the Bored Tunnel Alternative and the other Program elements combined with those of other past, present, and reasonably foreseeable future projects may result in cumulative effects on earth and groundwater. The project team considered 39 projects (shown in the project-specific cumulative effects matrix in Attachment A) for potential activities that could have a cumulative effect on earth or groundwater in Seattle.

Of the 39 projects considered, 2 projects associated with the Program were determined to have potential cumulative effects on earth and groundwater based on their location and planned construction:

- First Avenue Streetcar Evaluation
- S. Holgate Street to S. King Street Viaduct Replacement Project

If the First Avenue Streetcar is constructed before the bored tunnel, then settlement caused by tunnel boring could affect the operation of the streetcar.

If dewatering of the south portal area excavations and/or utilities for the Bored Tunnel Alternative occurs at the same time as dewatering of utility trenches for the S. Holgate Street to S. King Street Viaduct Replacement Project, a cumulative effect could be drawdown of the water table around the excavations in this area. Drawdown of the water table could lead to settlement of adjacent structures, utilities, and roadways. Recharge of the groundwater is planned for both projects to mitigate this effect; however, coordination between the two projects would be necessary to maintain the water table in the project area.

One other project is located within 200 feet of the proposed bored tunnel alignment and may have construction that occurs at the same time as construction of the Bored Tunnel Alternative. The Bill and Melinda Gates Foundation Campus Master Plan in the north portal area includes excavations that would be within 200 feet of the Bored Tunnel Alternative. However, because the water table in this area is located more than 50 feet below the ground surface, dewatering is not anticipated. Therefore, no cumulative effects on earth and groundwater related to this project are anticipated.

The other projects included in the project-specific cumulative effects matrix (in Attachment A) were determined to have no cumulative effects on earth and groundwater because they are greater than 200 feet from the bored tunnel alignment and/or construction of the projects is planned for either before or after construction of the Bored Tunnel Alternative.

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ATTACHMENT A

Cumulative Effects Analysis

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CUMULATIVE EFFECTS ANALYSIS

This cumulative effects analysis follows *Guidance on Preparing Cumulative Impact Analyses*, published by Washington State Department of Transportation (WSDOT) in February 2008. The guidance document was developed jointly by WSDOT, Federal Highway Administration (FHWA) – Washington Division, and U.S. Environmental Protection Agency – Region 10. The guidance can be used for FHWA's National Environmental Policy Act (NEPA) compliance (Code of Federal Regulations, Title 23, Part 771) and fulfillment of Washington State Environmental Policy Act (SEPA) requirements for evaluation of cumulative effects (Washington Administrative Code, Section 197-11-792).

The approach provided in the WSDOT guidance calls for early consideration of cumulative impacts while direct and indirect effects are being identified, preferably as part of the scoping process. For analysis, the guidance recommends the use of environmental documents such as discipline reports, as well as other relevant information such as local comprehensive plans, zoning, recent building permits, and interviews with local government. The guidance also advocates a partnership approach among agencies that includes early collaboration and integrated planning activities.

The guidance established eight steps to serve as guidelines for identifying and assessing cumulative impacts. These eight steps have been used in the following cumulative effects evaluation for the Bored Tunnel Alternative of the Alaskan Way Viaduct Replacement Project (the project). A matrix that identifies projects with the potential for cumulative effects with this project and an assessment of likely contributions to cumulative effects is also included.

Step 1. Identify the resource that may have cumulative impacts to consider in the analysis

Earth

Step 2. Define the study area and timeframe for the affected resource

The study area for the cumulative effects analysis is generally within about one city block (about 300 to 400 feet) from the perimeter of the Bored Tunnel Alternative alignment. The southern limit is S. Royal Brougham Way, and the northern limit is Roy Street.

Cumulative effects on earth are generally related to the construction period when earth and groundwater would be altered or moved. The construction duration for the Bored Tunnel Alternative is 2011 through 2017. As described in Step 5 below, operational effects for the Bored Tunnel Alternative are not expected to contribute to cumulative effects on earth; therefore, the timeframe considered was not extended beyond 2017.

Step 3. Describe the current health and historical context for each affected resource

The earth and groundwater resources of the central Puget Sound region have developed over millions of years through glaciations, volcanic activity, and other large-scale earth-moving events including earthquakes and landslides. During the early development of Seattle, extensive earth-moving projects included regrading hills and filling tidelands. Earth resources are likely to continue to be modified and affected by construction throughout the Program area as new buildings and roadways are built. No aquifers are present in the Program area. Until the 1890s, Seattle relied on small, privately-owned wells, springs and distribution systems for its water supply. Since 1901 the City's water needs have been met through the City's water system, which relies heavily on surface water sources lakes and rivers located far outside the Program area. There are currently several industrial water wells located near the Program area, but drinking water is supplied only through the City's municipal water system.

The subsurface geology encountered along the project alignment includes glacial deposits overlain by various thicknesses of recent native deposits (deposited through geologic processes) and fill (deposited by humans). Along most of the bored tunnel alignment, the glacial deposits are located within about 20 feet of the ground surface. In general, the deepest recent deposits are in the south portal area. These south portal area deposits extend from about 30 to 90 feet below the ground surface, and consist of loose to dense sand, silty sand, sandy silt, and soft to stiff clayey silt and silty clay. Within the fill deposits, debris such as wood and concrete are routinely encountered. Groundwater along the project alignment ranges from an elevation of about 2 feet below ground surface (bgs) to nearly 150 feet bgs with the average depth between about 70 and 80 feet bgs. These recent deposits are susceptible to liquefaction or strength loss during a seismic event.

Step 4. Identify the direct and indirect impacts that may contribute to a cumulative impact

No operational effects identified in this discipline report are anticipated to contribute to a cumulative effect. Many of the construction effects identified in this discipline report would also not contribute to a cumulative effect because best management practices (BMPs) would be used during construction of the Bored Tunnel Alternative and other adjacent projects, as required by city and state regulations. The following construction effects may contribute to a cumulative effect on earth and groundwater:

- Construction dewatering for excavations may lower the water table. This could result in settlement of buildings and other adjacent facilities if recharge of the water table is not performed.
- Ground loss could occur during construction of the bored tunnel. This ground loss could lead to settlement at the ground surface, which would affect existing structures, utilities, and other facilities.

Step 5. Identify other historic, current, or reasonably foreseeable actions that may affect resources

The project team considered 39 projects (shown in the project-specific cumulative effects matrix at the end of this attachment) for potential activities that could have a cumulative effect on earth or groundwater in Seattle. The following projects were identified as having potential cumulative effects on earth and groundwater based on their location and planned construction:

- **B4.** First Avenue Streetcar Evaluation
- **C1.** S. Holgate Street to S. King Street Viaduct Replacement Project

Projects not listed above were determined to either be outside of the study area or outside the timeframe of construction of the Bored Tunnel Alternative (2011 through 2017).

Step 6. Assess potential cumulative impacts to the resource; determine the magnitude and significance

See the project-specific cumulative effects matrix for identification of the cumulative effects.

Step 7. Report the results

The primary cumulative effects related to earth and groundwater are potential ground loss during tunnel boring and potential water table drawdown due to excavation dewatering. Both of these effects can cause settlement of the ground surface, structures, utilities, and roadways above and adjacent to tunnel construction.

Potential ground loss at the tunnel face during tunnel boring can migrate to the ground surface and cause settlement of buildings and other structures. Any other projects located within the potential surface settlement area caused by ground loss at the tunnel face could be affected. The shape of the surface settlement area typically resembles an inverted normal probability curve with maximum settlements over the tunnel centerline and a total width of about 1.5 to 2 times the tunnel depth. In areas where the tunnel is less than 100 feet from the ground surface, the settlement area can be narrower with larger settlements over the tunnel centerline. The shape and magnitude of the settlement area depend on the size and depth of the tunnel, the tunneling methods and workmanship used, and the subsurface conditions. In general, settlement over the centerline of the tunnel is largest when the depth of soil cover is smallest.

Three projects located over or immediately adjacent to the bored tunnel include the Alaskan Way surface street improvements, the Elliott Bay Seawall Project, and the First Avenue Streetcar Evaluation. In general, ground settlement due to tunneling is not anticipated to have a cumulative effect with these projects on the earth and groundwater. If the First Avenue Streetcar Evaluation is constructed before tunnel boring is performed, then settlement of the ground surface may affect the operation of the First Avenue streetcar. Construction traffic may also cause settlement, displacement, and other damage to existing roadways used by the First Avenue streetcar.

Excavations extending below the groundwater table typically require that dewatering of the water table be performed. Dewatering around excavations can result in drawdown of the water table. Drawdown of the water table increases the stress on subsurface soils, causing the soils to compress and settle. In the south portal area the subsurface soils are relatively soft and compressible, and the groundwater table is located within about 12 feet of the ground surface. The S. Holgate Street to S. King Street Viaduct Replacement Project may require excavations and dewatering at the same time as the approach excavations for the Bored Tunnel Alternative. This may result in increased effects on the water table.

Step 8. Assess and discuss potential mitigation issues for all adverse impacts

Mitigation measures identified for the project effects would be appropriate to address the cumulative effects. For groundwater dewatering and recharge, coordination between the Bored Tunnel Alternative and other projects performing dewatering and recharge will be needed. Dewatering rates and recharge may need to be adjusted to maintain the water table to within acceptable levels.

The following matrix identifies project-specific cumulative effects.

PROJECT-SPECIFIC CUMULATIVE EFFECTS MATRIX

PROJECT	POTENTIAL CUMULATIVE EFFECTS
A. Roadway Elements	
A1. Alaskan Way Surface Street Improvements – S. King Street to Pike Street	The bored tunnel alignment is located along Alaskan Way between S. King Street and Yesler Way. Ground loss may occur during tunnel boring, which could cause settlement of Alaskan Way. However, since the surface street improvements will be performed after the tunnel is constructed, no cumulative effects on earth and groundwater are anticipated.
A2. Elliott/Western Connector – Pike Street to Battery Street	No cumulative effects on earth and groundwater are anticipated because this project is located more than 200 feet away from the Bored Tunnel Alternative.
A3. Mercer West Project – Mercer Street becomes two-way from Fifth Avenue N. to Elliott Avenue, and Roy Street becomes two-way from Aurora Avenue to Queen Anne Avenue N.	No cumulative effects on earth and groundwater are anticipated because this project is located more than 200 feet away from the Bored Tunnel Alternative.
B. Non-Roadway Elements	
B1. Elliott Bay Seawall Project	The bored tunnel is located adjacent to the existing seawall between S. Washington Street and Yesler Way. Ground loss may occur during tunnel boring, which could cause settlement of the seawall. However, since the seawall will be replaced, no cumulative effects on earth and groundwater are anticipated.
B2. Alaskan Way Promenade/Public Space	No cumulative effects on earth and groundwater are anticipated because this project is located more than 200 feet away from the Bored Tunnel Alternative.
B3. Transit Enhancements – 1) Delridge RapidRide 2) Additional service hours on West Seattle and Ballard RapidRide lines 3) Peak hour express routes added to South Lake Union and Uptown 4) Local bus changes to several West Seattle and northwest Seattle routes 5)Transit priority on S. Main and/or S. Washington Streets between Alaskan Way and Third Avenue 6) Simplification of the electric trolley system	No cumulative effects on earth and groundwater are anticipated because there is little or no subsurface disturbance planned for the transit enhancements.
B4. First Avenue Streetcar Evaluation	The bored tunnel would pass beneath the proposed alignment of the First Avenue Streetcar. Ground loss may occur during tunnel boring, which could cause settlement of the ground surface along First Avenue. This may affect the construction of the First Avenue Streetcar Evaluation.

PROJECT-SPECIFIC CUMULATIVE EFFECTS MATRIX (CONTINUED)

PROJECT	POTENTIAL CUMULATIVE EFFECTS
C. Projects Under Construction	
C1. S. Holgate Street to S. King Street Viaduct Replacement Project	If dewatering of the south portal area excavations and/or utilities occurs at the same time as dewatering of utility trenches for this project, a cumulative effect could be drawdown of the water table around the excavations. Drawdown of the water table could lead to settlement of adjacent structures, utilities, and roadways. Recharge of the groundwater is planned for both projects to mitigate this effect; however, coordination between the two projects would be necessary to maintain the water table in the project area.
C2. Transportation Improvements to Minimize Traffic Effects During Construction	No cumulative effects on earth and groundwater are anticipated because there is no subsurface disturbance planned for the transit enhancements.
D. Completed Projects	
D1. SR 99 Yesler Way Vicinity Foundation Stabilization (Column Safety Repairs)	No cumulative effects on earth and groundwater are anticipated because this project is already complete, and cumulative effects for earth are related to construction overlaps.
D2. S. Massachusetts Street to Railroad Way S. Electrical Line Relocation Project (Electrical Line Relocation Along the Viaduct's South End)	No cumulative effects on earth and groundwater are anticipated because this project is already complete, and cumulative effects for earth are related to construction overlaps.
E. Seattle Planned Urban Development	
E1. Gull Industries on First Avenue S.	No cumulative effects on earth and groundwater are anticipated because this project is located more than 200 feet away from the Bored Tunnel Alternative.
E2. North Parking Lot Development at Qwest Field	No cumulative effects on earth and groundwater are anticipated because this project is located more than 200 feet away from the Bored Tunnel Alternative.
E3. Seattle Center Master Plan (EIS) (Century 21 Master Plan)	No cumulative effects on earth and groundwater are anticipated because this project is located more than 200 feet away from the Bored Tunnel Alternative.
E4. Bill and Melinda Gates Foundation Campus Master Plan	Excavations are planned for this project that would be within 200 feet of the Bored Tunnel Alternative. However, because the water table in this area is located over 50 feet below the ground surface, dewatering is not anticipated. Therefore, no cumulative effects on earth and groundwater are anticipated related to this project.
E5. South Lake Union Redevelopment	No cumulative effects on earth and groundwater are anticipated because these projects are located more than 200 feet away from the Bored Tunnel Alternative.
E6. U.S. Coast Guard Integrated Support Command	No cumulative effects on earth and groundwater are anticipated because this project is located more than 200 feet away from the Bored Tunnel Alternative.
E7. Seattle Aquarium and Waterfront Park	No cumulative effects on earth and groundwater are anticipated because this project is located more than 200 feet away from the Bored Tunnel Alternative.
E8. Seattle Combined Sewer System Upgrades	No cumulative effects on earth and groundwater are anticipated because this project is located more than 200 feet away from the Bored Tunnel Alternative.

PROJECT-SPECIFIC CUMULATIVE EFFECTS MATRIX (CONTINUED)

PROJECT	POTENTIAL CUMULATIVE EFFECTS
F. Local Roadway Improvements	
F1. Bridging the Gap Projects	These projects primarily involve roadway resurfacing. Since subsurface disruption is limited to a few feet, no cumulative effects on earth and groundwater are anticipated.
F2. S. Spokane Street Viaduct Widening	No cumulative effects on earth and groundwater are anticipated because this project is located more than 200 feet away from the Bored Tunnel Alternative.
F3. SR 99/East Marginal Way Grade Separation	No cumulative effects on earth and groundwater are anticipated because this project is located more than 200 feet away from the Bored Tunnel Alternative.
F4. Mercer East Project from Dexter Avenue N. to I-5	No cumulative effects on earth and groundwater are anticipated because this project is located more than 200 feet away from the Bored Tunnel Alternative.
G. Regional Roadway Improvements	
G1. I-5 Improvements	No cumulative effects on earth and groundwater are anticipated because these projects are located more than 200 feet away from the Bored Tunnel Alternative.
G2. SR 520 Bridge Replacement and HOV Program	
G3. I-405 Corridor Program	
G4. I-90 Two-Way Transit and HOV Operations, Stages 1 and 2	
H. Transit Improvements	
H1. First Hill Streetcar	No cumulative effects on earth and groundwater are anticipated because these projects are located more than 200 feet away from the Bored Tunnel Alternative.
H2. Sound Transit University Link Light Rail Project	
H3. RapidRide	
H4. Sound Transit North Link Light Rail	
H5. Sound Transit East Link Light Rail	
H6. Washington State Ferries Seattle Terminal Improvements	This project is primarily over water and would have no effect on earth or groundwater.
I. Transportation Network Assumptions	
I1. HOV Definition Changes to 3+ Throughout the Puget Sound Region	No cumulative effects on earth and groundwater are anticipated because there is no subsurface disturbance planned for these projects.
I2. Sound Transit Phases 1 and 2	
I3. Other Transit Improvements	

PROJECT-SPECIFIC CUMULATIVE EFFECTS MATRIX (CONTINUED)

PROJECT	POTENTIAL CUMULATIVE EFFECTS
J. Completed but Relevant Projects	
J1. Sound Transit Central Link Light Rail (including the Sea-Tac Airport extension)	The Bored Tunnel Alternative does not have operational effects that would contribute to cumulative effects on earth and groundwater. Since this project is complete, no cumulative effects on earth and groundwater are anticipated. Also, this project is not located in the study area.
J2. South Lake Union Streetcar	The Bored Tunnel Alternative does not have operational effects that would contribute to cumulative effects on earth and groundwater. Since this project is complete, no cumulative effects on earth and groundwater are anticipated. Also, this project is not located in the study area.
J3. SR 519 Intermodal Access Project, Phase 2	This project was completed prior to start of major excavation for the Bored Tunnel Alternative. Since cumulative effects for earth are related to construction overlaps, no cumulative effects are anticipated.